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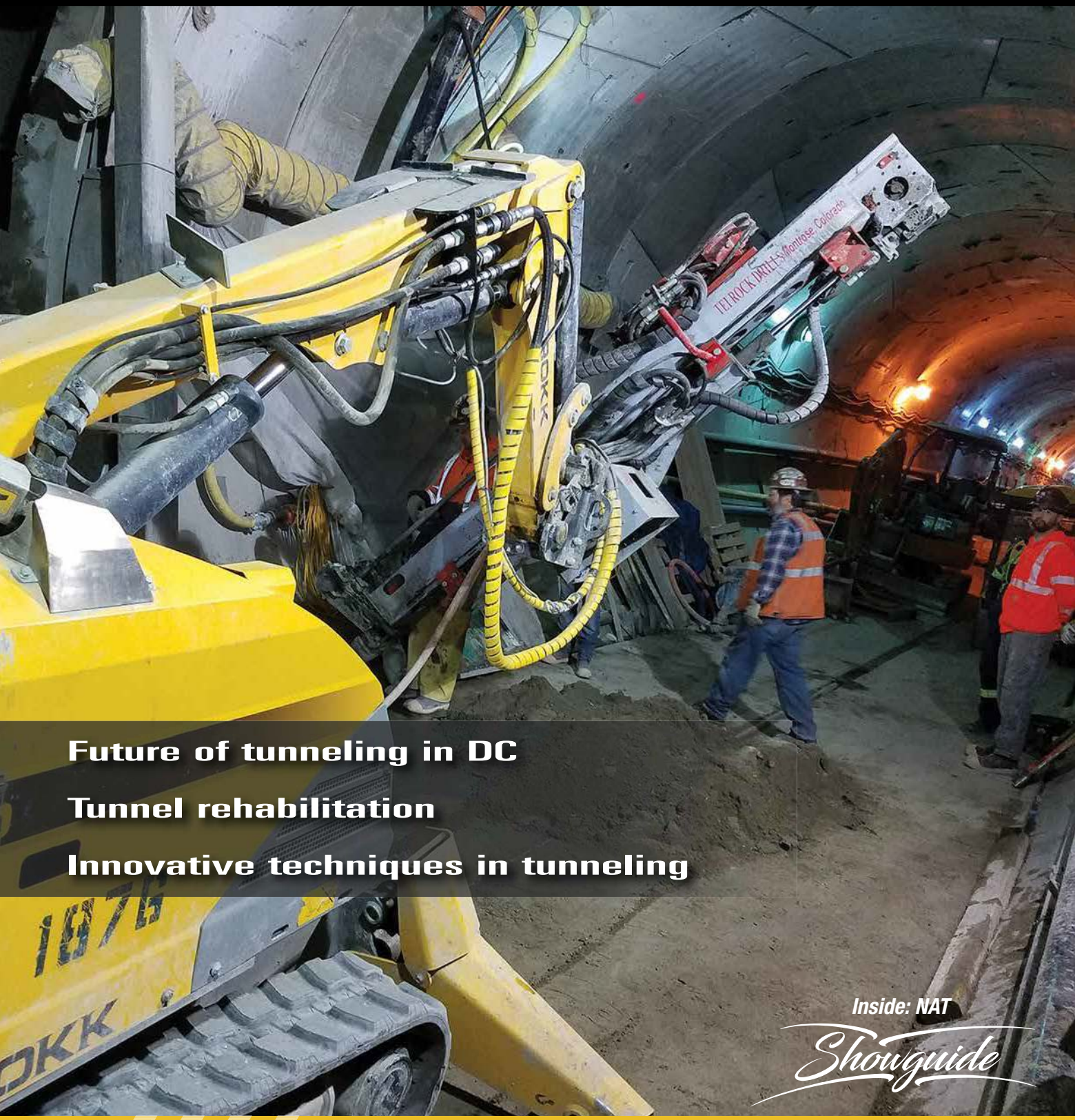

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AN OFFICIAL PUBLICATION OF UCA OF SME WWW.SMENET.ORG VOLUME 12 NO 2 JUNE 2018

COVER STORY

In this issue —
By the time the expansion of the Metro in Washington, D.C. is completed in 2020, the system will serve 97 stations and operate 117 miles of track. The future of tunneling in D.C. is discussed on page 12. Is it cheaper to rehabilate an existing tunnel instead of boring a new one? That issue is discussed from an owner's perspective on page 20.

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DEPARTMENTS

CHAIRMAN'S COLUMN

World Tunnel Congress and the 2018 NAT Conference

I've recently returned from the 2018 World Tunnel Congress and 44th ITA General Assembly in Dubai, U.A.E. It was my privilege and honor to represent all UCA of SME members at the General Assembly. This year's theme was "The Role of Underground Space in Building Future Sustainable Cities." This was an appropriate theme, considering that Dubai is a bustling and majestic city rising out of the desert. And yes, they do tunnel under the desert.

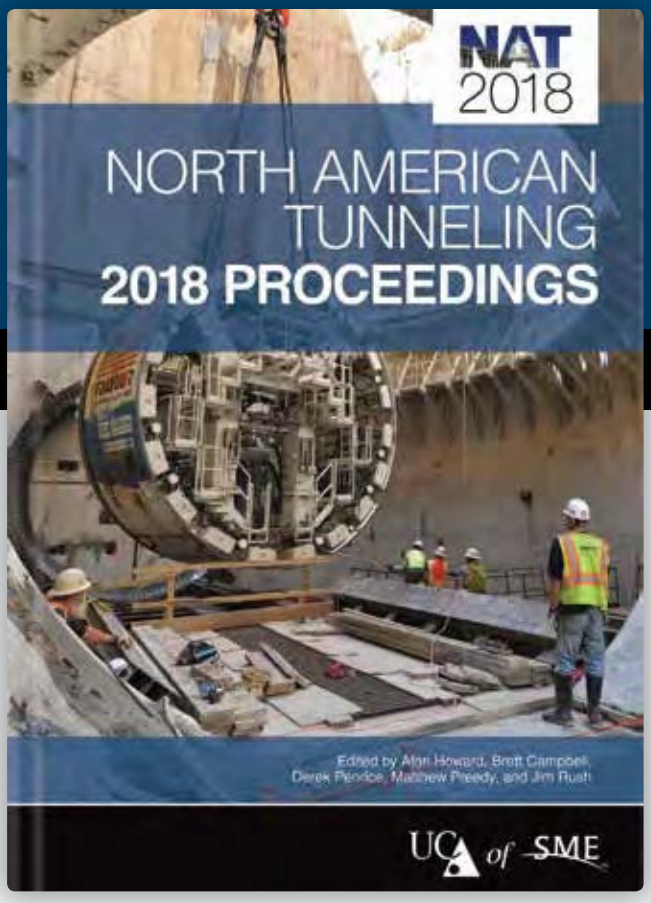
The United States was well represented, with 38 delegates and seven exhibitors attending. Additionally, UCA members participated in 10 of the 14 active ITA Working Groups. One of the many important functions of these groups is the collection and dissemination of innovations and experiences from the global tunneling industry.

A highlight of the Congress is the annual Sir Alan Muir Wood Lecture. Ed Cording had previously been selected to present this year's lecture, entitled, Monitoring and Controlling Ground Behavior at the Source. Ed's lecture began by describing the development of ground control techniques using modern pressurized-face tunnel boring machines (TBM). This included several high-profile projects that many of our membership were involved with. He then explained how all of these past lessons and developments, good and bad, were brought to bear for the successful completion of Seattle's SR-99 project.

While attending WTC, a few of us were invited to sit in on a meeting of the Nordic Forum. This group is comprised of the delegates from primarily Scandinavian countries. This is their opportunity to share interests and practices specific to their region. The Nordic Forum meets a few times per year, either in person or electronically. Following this meeting, those of us attending from the U.S. felt that such a forum could be beneficial to the United States tunneling industry. Accordingly, we reached out to delegates from Canada and South America, receiving warm reception to the concept. Over the next couple of months, members of the UCA will begin to explore what such an alliance of the Americas could accomplish to the mutual benefit of all member nations. Please contact me if you would like to be a member of this exploratory committee.

Soon we will all be together in Washington, D.C. for the 2018 North American Tunneling (NAT) Conference. As always at NAT, the offerings include short courses, technical sessions, panel discussions, technical field trips and exhibits from the many suppliers and subcontractors that service our industry. Given the location of this year's conference, we have been working to attract decision makers from Capital Hill. We all know of looming projects that could use some legislative support to move them closer to reality. I ask that you reach out to your representatives and ask them to attend. We may just aides and assistants, but they, too, are capable of carrying a torch. ■

Mike Roach,
UCA of SME Chairman



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California WaterFix gets funding promise

The massive California WaterFix tunnel project might have gotten new life when the board of the Metropolitan Water District of Southern California, the largest water agency in the state, voted to bear most of the $11 billion cost to get the project started.

The project, which calls for two tunnels under the Sacramento-San Joaquin Delta to move water from the north to the southern part of the state, was in jeopardy after San Joaquin Valley agriculture districts that were supposed to pick up nearly half of the $17-billion tab backed out. The vote by the Metropolitan Water District of Southern California was seen as an 11th hour rescue of the project. However, it does not guarantee that the project will be built and was not without controversy.

"This vote was honestly quite divisive," Los Angeles board member Mark Gold told the *Los Angeles Times*. "The Metropolitan Water District is basically subsidizing benefits for the entire state of California over and above the 19 million customers that Met has in Southern California. … To have local ratepayers incur that risk is inappropriate and potentially illegal."

State constitutional provisions requiring local government fees to be proportional to the services provided could leave MWD vulnerable to court challenges, Gold and others warn.

According to MWD, financing the twin tunnels would add an average of $60 a year to household water rates across the Southland. But local purchases of agency supplies vary, meaning costs will vary too.

Backers are worried that a plan to downsize the project to one tunnel would drag out the permitting process beyond the end of the year, when Gov. Jerry Brown — WaterFix's chief political cheerleader — would be out of office. His successor might not be so enthusiastic about the tunnels, which are opposed by delta interests and major environmental groups.

The Los Angeles Times reported that of the leading candidates for Brown's office two are in favor of the one-tunnel option with an emphasis on finding other solutions to the water problem while others in the race are flatly opposed to the tunnels.

Moving ahead with just one tunnel would "risk serious delay … and jeopardize the entire project," Brown wrote to the directors on the eve of the vote.

After the San Joaquin Valley agriculture backed out, the state was prompted to shrink the proposal to a cheaper, one-tunnel version that would be financed by MWD and the other, mostly urban districts that get State Water Project deliveries from the delta.

Under that scenario, WaterFix would move ahead in stages, with a second tunnel built when financing materialized. Not long after the downsizing proposal emerged, MWD started talking about picking up agriculture's unfunded portion, with the assumption that the agency could recoup the extra cost by selling tunnel capacity to growers after the project is built.

But there is no guarantee agricultural districts will buy tunnel supplies — or if they do, that they will pay a price that reflects the water's true cost. ■

New tunnel planned for Minneapolis

The tunnels that were built beneath the city of Minneapolis, MN to carry storm water from the city to the Mississippi River are about 80 years old and can no longer handle the job alone.

Like many large cities, Minneapolis has grown beyond its original infrastructure in recent years. The city is hoping to gain support of city council members to fund a $38 million project that would dig a new tunnel next to the existing one.

The $38 million project will dig a new passage 21 to 30 m (70 to 100 ft) beneath Washington Avenue. It would be the largest project of its kind downtown since the system was built about 80 years ago. The city has been fixing its tunnels for about a decade to head off mishaps like a 2010 sewage spill into the river, caused by surging rainwater beneath 2nd Avenue that burst through a liner into a nearby sewer.

The *Minneapolis Star Tribune* reported that the urban center of the Twin Cities is crisscrossed by subterranean passages that make day-to-day life possible above ground. Carved through the softer material below a layer of limestone, in places as deep as 11 stories, these tunnels use gravity to deliver water to the river or to a sewage treatment plant.

The city has been giving underground tours to city council members and legislators to make the case for fixing an unseen problem. Minneapolis is seeking $19 million from the state legislature to defray the cost of its Washington Avenue project, which could begin construction in 2020.

"The tunnels were built to handle much less water, so even when it's raining moderately it means they're full," said Katrina Kessler, the city's director of surface water and sewers, on a tour of a tunnel in southeast Minneapolis.

The project wasn't included in Gov. Mark Dayton's bonding bill, and neither the House nor the Senate has released its bonding proposal. It

(Continued on page 10)

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Elon Musk invests $100 million into the Boring Co.

When Elon Musk vowed to begin boring tunnels beneath the streets of Los Angeles, CA it seemed unlikely that much would come from the tweet. And when he began to raise money for the new venture by selling hats and flamethrowers it certainly raised some doubts. But when it was reported that he has raised more $110 million for the Boring Co., it looks as if this is more than a billionaire frustrated by traffic.

The *Los Angeles Times* and other outlets reported that Musk, the founder of Tesla and SpaceX, raised $112.5 million in a recent funding round, according to a document filed with the U.S. Securities and Exchange Commission.

Most of the money — more than 90 percent — came from Musk himself. The rest was from "early employees" of the company, according to the Boring Co.

The company said no venture capitalists or outside investors were involved in this round.

The funding round is a more conventional method of fundraising than Musk's most recent money-maker — sales of flamethrowers. Musk said in January that the Boring Co. had pre-sold 10,000 flamethrowers branded with the company logo for $500 apiece. He also said at the time that he sold about 3,000 fire extinguishers for $30 each.

The flamethrower and fire extinguisher sales came after a similar, though less flashy, fundraiser by Musk to sell 50,000 Boring Co. branded hats for $20 each.

The Boring Co. has said its goal is to increase the speed and lower the price of digging tunnels to reduce traffic congestion.

The company has already dug a tunnel across from SpaceX's headquarters with a boring machine it purchased. Musk said the company's tunnels and Hyperloop plans would prioritize pedestrians and cyclists over cars. Passengers would load into a pod with large windows that's lowered underground before it speeds on a track, according to a video Musk tweeted in March.

"Will still transport cars, but only after all personalized mass transit needs are met," Musk tweeted March 9. "It's a matter of courtesy & fairness. If someone can't afford a car, they should go first."

The company says tunnel-digging projects can cost as much as $1 billion per mile, but its goal is to lower these costs by a factor of 10 or more.

In October 2017, the Maryland Department of Transportation gave "conditional approval to the construction of a tunnel from Baltimore to Washington" for the project by issuing a utility permit.

In March, six Democratic members of Congress from Maryland and Washington wrote to Maryland Gov. Larry Hogan seeking information about the state's support for the proposed Hyperloop Project, including the regulatory standards that will apply.

"While the Hyperloop is an exciting project that has the potential to transform transportation along the entire U.S. East Coast, it is also a project that would utilize a wholly new technology and could have significant impacts on our constituents," the members wrote. ■

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BART extension to San Jose approved

A long-awaited transit tunnel extension to San Jose, CA was approved by the Bay Area Rapid Transit (BART) Board of Directors in April.

In a 5-0 vote, the board approved a single-bore tunneling plan that the Santa Clara Valley Transportation Authority says will be faster and less disruptive to San Jose traffic.

Previously, BART planners had wanted to go with a more traditional dual-tunnel approach to the San Jose dig, and the disagreement put the $4.8-billion project into a holding pattern.

An editorial in the *San Jose Mercury News* supported the single bore plan, writing, "The technology allows the boring machine to dig deeper underground, without tearing up streets and disrupting traffic flow. It also should cut 10 months off the four-year tunneling phase and drop the total price tag by an estimated $50 million.

"The twin-tunnel approach originally supported by BART's staff would have involved ripping up Santa Clara Street, from Market Street to Third Street, for a period of three years. The cut-and-cover process would have required relocating complex utility networks, frequently causing construction delays."

The VTA board approved the tunnel plan earlier in May. The extension may qualify for federal grants that cover nearly a third of its costs.

Director Thomas Blalock recorded some reservations about the methods, predicting that a single tunnel would result in smaller stations and platforms that BART riders might regret down the line.

"Those platforms are going to limit capacity in Santa Clara County," warned Blalock. But in the end, he was among those who voted yes on the proposal.

Writing in 2010, transit news site *The Source* noted that the single-bore method is the result of new technology and larger digging machines like those that could be used on this project.

Under the present timeline, construction to San Jose would begin toward the end of 2020, and the first passenger service would happen come 2026. The full 25-km (16-mile) plan involves six new stations, from Milpitas to Santa Clara. ■

CALL for PAPERS

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The 2019 RETC Organizing Committee has issued a **call for papers**. Prospective authors should submit the following by **June 30, 2018**: Abstract of 100 words to

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Deadline is June 30, 2018

Authors will be notified of acceptance by September 2018. Final manuscripts from accepted authors are due December 15, 2018. Manuscripts are mandatory for inclusion and must be received on time. All manuscripts will be included in the proceedings volume distributed on-site to all full registrants. If you cannot commit to completing a manuscript on time, please do not submit an abstract for consideration.

Tunneling to begin on LA Metro's Purple Line

Tunneling for the first phase of Metro's Purple Line Extension project will begin later this summer under the Miracle Mile. Two tunnel boring machines, named Elsie and Soyeon were unveiled on April 24, the local *CBS* affiliate in Los Angeles, CA reported.

The two boring machines will begin by digging parallel tunnels underneath Wilshire Boulevard between Koreatown and Beverly Hills to connect three new stations and 6.3 km (3.92) miles of new rail.

The full extension of the project that initially broke ground in late 2015 includes three phases, and will add about 14.5 km (9 miles) and seven new stations extending to the Westside, taking riders from downtown Los Angeles to Westwood in about 25 minutes.

The project, expected to cost $8.2 billion, is considered to be one of Metro's priority projects.

"The Wilshire corridor has the highest population and employment density of any transportation corridor in Los Angeles," said Mayor Eric Garcetti.

"For all the people who live and work here, the Purple Line Extension will create faster and more convenient ways to get to work and get back home to their loved ones," added Garcetti.

Boring each tunnel on the first phase will take about two years to complete.

It's scheduled to be finished and ready for riders in 2023.

Sections 1 and 2 are funded primarily by Measure R, the sales tax Los Angeles County voters approved in 2008. ■

Minneapolis: Stormwater tunnel

(Continued from page 4)

is third on the city's list of bonding priorities, behind an overhaul of the Upper Harbor Terminal property and an expansion of the city's emergency operations and training facility.

The tunnels are significantly deeper than the other essential conduits beneath the sidewalks. Most gas, electric and communications lines on Nicollet Mall are 1 to 1.5 m (3 to 5 ft) below ground, just above water mains and sewer pipes.

Once stormwater drops to the tunnels, it flows by gravity toward Washington Avenue, where it follows the street's path underground for several blocks before being spit out into the river beside the Stone Arch Bridge. The tentative plan is to build another tunnel beside the existing one to reduce pressure across the downtown system.

It's not the only deep tunnel work happening in the city. The Minnesota Department of Transportation has spent nearly four years burrowing 36 m (120 ft) below Interstate 35W in south Minneapolis and repairing its stormwater tunnels there. And the Metropolitan Council is preparing to repair a wastewater tunnel near Minnehaha Park that's as deep as 22 m (74 ft) underground.

Including tunnels outside downtown, the city's system spans nearly 26 km (16 miles), ushering rainwater from about a fifth of the city to the river. St. Paul has 32 km (20 miles) of tunnels that perform a similar task.

Since 2009, Minneapolis has spent $2 million to $5 million a year largely on repairing breaks in the lining. Pressurized water over time fractures the concrete, creating voids in the surrounding sandstone that further compromise the tunnels' strength.

St. Paul has spent about $3.5 million to $4 million per year since 2006 on rehab work, said Bruce Elder, the city's sewer utility manager. It is now working on a Phalen Creek tunnel northeast of downtown.

"We're more or less working within the existing tunnel and making repairs," Elder said. "We don't really have a great need for additional capacity." ■

Epiroc introduces new hydraulic breakers

While incorporating the popular features of Epiroc's market-leading Solid Body (SB) breaker range, the new SB 302 and SB 452 Tunnel versions provide application-specific modifications that extend equipment lifetime and reduce overall operating costs in underground applications.

Piston lifetime in the advanced Tunnel version is extended by a new piston in stainless steel, while bushing seat wear is minimized by a press-fit, one-piece bushing locked by an additional pin. An exchangeable wear plate protects the hammer body and durability is enhanced by heavy duty retainer bars and a locking pin.

The special tunneling tool with a collar supporting a robust front shield and dust cover minimizes the dust intake when working on overhead areas. Two restrictors are available that enable the performance of the hydraulic breaker to be adjusted for either traditional scaling operations or for more challenging rock breaking jobs.

Together, these new features add up to less wear, extended lifetime and lower overall operating costs in scaling, tunneling and underground mining applications. ■

Keller and Hayward Baker acquires Moretrench

Keller and Hayward Baker have acquired New Jersey-based Moretrench, a contractor operating predominantly along the east coast of the United States and with a strong heritage of complex geotechnical projects. Moretrench will operate as a division within Hayward Baker. The enlarged entity will be well-positioned for the expected long run renewal of infrastructure.

Eric Drooff, president of Hayward Baker, noted that, "Having worked closely with Moretrench on several key projects, we were impressed with the quality of the company and expertise of its people. We are excited to welcome Moretrench to Hayward Baker and look forward to developing new synergies."

Hayward Baker and Moretrench both enjoy a strong and well-established presence in the tunneling and underground construction industry and each has worked extensively on major subway and other tunnel construction projects throughout North America. With each company contributing particular areas of expertise, and sharing others, together the company will bring to its clients the widest range of underground construction solutions available through any single geotechnical contractor.

Tom Tuozzolo, president of Moretrench, added, "As a division of Hayward Baker, we can now offer additional geotechnical solutions and resources to our established clients as well as extending our dewatering and ground freezing techniques to Hayward Baker's clients. This translates to more comprehensive and even better customer service for both our companies. I am excited to lead the Moretrench team forward into this new venture."■

Czech railway project will link Prague to European transport network

With the expansion of the railway line between Rokycany and Pilsen as a high-speed rail link, the Czech railway network is being modernized. The line in the western part of the Czech Republic is part of the railway corridor linking Pilsen to Prague and, thus, to the European railway network. Over a distance of 4.1 km (2.5 miles) it consists of two single-track tunnel tubes. The tubes were built by the Czech contractor Metrostav. For the first time in Eastern Europe, a convertible multi-mode tunnel boring machine (TBM) (from earth pressure balance (EPB) mode to single-shield mode) specifically designed and manufactured by Herrenknecht at its Schwanau plant, was used for the project.

The multi-mode TBM built two-thirds of the two tunnels through quartzite shale stone and clay soils in closed EPB mode with screw conveyor muck removal. On the last 1.1 km (0.7 miles) of each route, the machine S-799 had to penetrate hard spilite rock, for which it was converted to open single-shield mode with belt conveyor removal. Each of the conversions was realized inside the tunnel in just two weeks. "For variable ground conditions along the tunnel alignment, a convertible multi-mode TBM is the best and most flexible solution. It can be run in different tunneling modes and thus operate in changing geologies," explained Korbinian Kröger, responsible project manager at Herrenknecht.

The cutting tools were also changed for the second section of each drive and 48 cm (19 in.) disc cutters were installed for the single-shield mode section instead of the previously used 46 cm (18 in.) disc cutters. The larger disc diameter allowed higher contact pressure in the solid hard rock and longer running times. With small overburdens in parts, the flexible allrounder among the tunnel boring machines achieved weekly top advance rates of up to 182 m (597 ft). After 12 months, in October 2017 the site crew was able to celebrate the final breakthrough for the second tunnel tube. In addition to the TBM, Herrenknecht provided additional equipment, such as multi-service vehicles from subsidiary TMS, a cooling tower and belt conveyor systems.

The new high-speed rail link reduces the average travel time between Rokycany and Pilsen by around 10 minutes, and the capital city of Prague can be reached from Pilsen in less than one hour. As a result the region around Pilsen – with about 170,000 inhabitants the fourth largest city in the Czech Republic – will be better connected to the trans-European transport network. The modernization project not only makes the railway line faster, but also brings it up to the state of the art. This includes, for example, special safety features such as fire protection solutions and escape routes in the new tunnels.

Herrenknecht is also involved in other infrastructure development projects in Eastern Europe. They include Poland's largest tunnel structure – the 10-km (6.1-mile) long Slowacki Route in Gdansk. ■

FEATURE ARTICLE

The future of transit tunneling in Washington, D.C.

Brian Zelenko, Harald Cordes and William H. Hansmire

Brian Zelenko, Harald Cordes and William H. Hansmire, members UCA of SME, are vice president, engineering manager and senior vice president with WSP USA, email brian.zelenko@wsp.com.

By the time the latest expansion of the Washington Metropolitan Area Transit Authority (WMATA) system, known locally as Metro and which opened in 1976, is completed in 2020, the system will serve 97 stations and operate on 188 km (117 miles) of track on six interconnecting lines. Metro provides a critical transportation link to a population of approximately six million people within a 3,900-km^2 (1,500-sq-mile) Washington Metropolitan area and has allowed job growth to expand to all corners of the region. In the 1950s and 1960s, when the system was first conceived and construction began, most jobs were centered in downtown Washington, and most of the workforce commuted by bus or car. Today, transit-oriented development has increased residential, commercial and government facilities near most of the existing 91 stations increasing the importance of the Metro system as a critical transportation link for the region. According to recent American Public Transportation Association (APTA) data, Metro is the second busiest transit system in the United States (after New York City's transit system).

During the nearly 50 years of construction on the Washington Metro system, technology improvements and lessons learned from the global tunneling industry were implemented. Portions of this background and history have been adapted from other work by the authors Roach et al. (2017) and expanded for use herein. For soil tunnels, these improvements included the change from a "two-pass" tunnel lining with a typical initial lining of steel ribs with wood lagging or segmental precast lining erected within the tunnel shield followed by a final lining of cast-in-place concrete to a one-pass lining system of pre-cast concrete gasketed segmental lining. Soil tunnels were originally excavated using open-face tunnel shields, but changed over time. By the late 1980s, tunneling using closed, pressurized-face tunnel boring machines (TBMs) using a one-pass tunnel lining consisting of segmental precast concrete permitted tunneling in a wider range of soil conditions with much less risk of damaging overlying utilities or structures, greater safety for tunnel construction personnel and without the need to dewater the soils. However, due to concerns about conditioning clays with earth pressure balance (EPB) TBMs, open face machines were still favored by contractors for their better advance rates, lower cost and ability to deal with boulders that were occasionally encountered in the Coastal Plain Terrace Deposits.

Ground improvement techniques that made tunneling possible in weak or very wet soils at the start of Metro construction were largely limited to cement and chemical grouting and, to a lesser extent, ground freezing. Many early (pre-1978) WMATA tunneling contractors used chemical grout for use in fine-grained soils. This changed over time as technologies evolved for jet grouting (replacement of soil by grout), compaction grouting and compensation grouting where grouting is undertaken as tunneling takes place.

For tunnels in rock, the work started when tunneling technologies were transitioning from the traditional method of drill-and-blast excavation with rock support using structural steel (steel sets) to more modern methods. The first rock tunnel running north from Dupont Circle Station was a single double-track tunnel excavated by drill-and-blast methods. Later, tunnel contractors used hard-rock TBMs between and through the stations. WMATA personnel had concerns about the delays associated with gripper-type TBMs getting stuck for extended periods in weak rock formations (there was no reverse gear) and with replacing worn disc cutters. Consequently, they preferred conventional rock excavation techniques. Drill-and-blast excavation continued out of necessity to excavate station caverns in rock, as well as many smaller-size excavations such as for cross-passages between tunnels.

Design and construction of rock tunnel linings evolved to follow principles of rock reinforcement by using rock bolts and shotcrete, eliminating the use of steel sets. These practices progressed further where rock bolts were replaced by untensioned rock dowels fully encapsulated with cement or resin and shotcrete for initial support and, in some cases, shotcrete as the permanent lining. Ground water leaks were a major problem during early construction. Dry tunnels without leaks became possible when PVC membranes were placed between the initial and final linings of rock tunnels (Sauer et al., 1987). It was part of the early introduction and adaptation of European tunneling methods and initial use in the United States (Heflin 1985) of the New Austrian Tunneling Method (NATM), also known as the sequential excavation method (SEM). This was the first time in the United States where the owner fully accepted the method and used it for later projects. This approach to tunneling integrated the several techniques that had evolved globally

over the years and was used to successfully excavate tunnels in rock and, for the first time in the United States soil (Heflin et al., 1991).

The contract for the Fort Totten Station and tunnels in 1988 was the only contract out of three offered by WMATA in which the contractor chose to utilize NATM. It was the first use of NATM in soft ground (sands and clays) for a transit tunnel in the United States. The project included 292 m (958 linear ft) of twin tunnels, in addition to a portion of the station excavation located west of the Fort Totten Station. Excavation and ground behavior were monitored during construction by an extensive geotechnical instrumentation program. Specified initial support included shotcrete applied in three stages, with welded wire fabric and lattice girders. Soil anchors were also required for initial support. Additional support was provided by forepoling bars, forepoling sheets and face shotcreting.

FIG. 1

Steel pipe arch canopy support for WMATA Silver Line extension in Tyson's Corner. Source: Vojtech Gall/GZ Consultants.

The tunnel research work that began on the first projects of the Washington Metro set the stage for geotechnical instrumentation and monitoring for tunneling that is undertaken throughout the world today. Metro engaged the University of Illinois at Urbana-Champaign Department of Civil Engineering to conduct field research on soil tunneling, rock tunneling and cut-and-cover excavations. The lessons learned for instrumentation and procedures for tunneling were published as Methods for Geotechnical Observations and Instrumentation in Tunneling (Cording et al., 1975).

Washington Metro engaged a board of experts to peer review and advise on all aspects of design and construction. The Washington Metro Tunnel Board of Consultants (including Ralph B. Peck, Don U. Deere and A. A. Mathews) became the forerunner for what is today a common practice within the underground industry (Roach et al., 2017).

Approximately half of the original 165-km (103-mile) system was constructed underground, including approximately 30 km (19 miles) of rock tunnels, 19 km (12 miles) of mined soft-ground tunnels and cut-and-cover construction. A total of 48 stations are underground, 11 of which were mined in rock, one was mined in soil, and the rest were constructed by cut-and-cover methods. The 30 km (19 miles) of rock tunnels were constructed for the Red Line extending from Dupont Circle Station north to the Rockville Station, approaches to and under the Potomac River between Foggy Bottom and Rosslyn Stations, and the north end of the Red Line between Wheaton and Glenmont Stations.

The local geology straddles the boundary between the Coastal Plain and the Piedmont Physiographic Provinces. From the boundary, also known as the Fall Line, which extends through the metropolitan area from SW to NE, there is an increasingly thickening wedge of Coastal Plain deposits to the southeast underlain by older Piedmont rocks. Coastal Plain soils include interbedded alluvial soils, ranging from clays, silts and sands to cobbles and boulders, deposited by rivers and tributary systems within channels, bars, floodplains, terraces and alluvial fans. The alluvial deposits are underlain by older Potomac Group soils, which were deposited in a marine environment and are generally denser and stiffer than the alluvial deposits. Northwest of the Fall Line, Piedmont residual soils, weathered and hard intact bedrock are evident near the ground surface. These geologic conditions had a significant influence on tunneling and underground construction methods. Also influencing construction were the presence of the Potomac and Anacostia Rivers, Rock Creek and other tributary streams and creeks.

Expansion of the system

In recent years, there have been several expansions of the original Metro system that have included tunneling and underground construction. These projects include the Dulles Corridor Metrorail, also known as the Silver Line, the Rosslyn Station Expansion and Access project, the Medical Center Station Metro Crossing project, and the Purple Line, a new light rail transit system overseen by the Maryland Transit Administration that will provide a circumferential connection between three suburban Metro Stations (Bethesda, Silver Spring and Greenbelt) in Maryland.

The Dulles Corridor Metrorail Project, estimated at more than $5 billion, extends Metro service from West Falls Church Station through Tysons Corner to Wiehle Avenue Station (Phase I) and to Dulles International Airport, terminating at a station beyond the airport in Loudoun County, VA (Phase II). SEM tunneling was employed for a 520 m (1,700 ft) section through Tysons Corner in Phase I of the project. SEM was used, including a single- and double-grouted steel pipe arch canopy pre-support due

FIG.2

DC Water's First Street Tunnel EPB TBM "Lucy" as introduced by Mayor Muriel Bowser. Source: Brian Zelenko/WSP at TBM Naming Ceremony on April 14, 2015.

to shallow cover and soft ground (Fig. 1). This design-build project, overseen by the Metropolitan Washington Airports Authority, is funded by various public and private entities, including the Dulles Toll Road, demonstrating how third parties can work together with WMATA to address regional transportation needs and expand the Metro system.

Rosslyn Station is an important underground hub station in Arlington, VA, that serves the Orange, Blue and Silver lines. The station was constructed in the early 1970s and was opened in 1977. As part of a new residential and commercial development, an access improvement project was undertaken in 2009 and completed in 2013 to accommodate expanded station capacity associated with the new development. The work included a new station entrance and a new track-level mezzanine that expands the passenger capacity of the station. Construction included a new vertical elevator and stair shaft entrance from the ground surface, connected by a 11-m (35-ft)-wide by 12-m (40-ft) high mezzanine constructed using SEM techniques leading toward the existing station. Passengers walk through a 6-ft (19-ft) wide by 4.5-m (15-ft) high passageway between the new concourse and the existing escalator entranceway. The SEM approach to design and construction made the complex underground structures possible.

The Rosslyn Station expansion is an excellent example of transit-oriented development leading to privately-financed expansions of the system. In Maryland, the Purple Line will include a new underground entrance to Metro's Bethesda Station to facilitate connectivity between Metro and the Purple Line.

Other recent and future tunneling in Washington, D.C.

The DC Water Clean Rivers Project is a $2.6-billion program to reduce the occurrence of combined sewer overflows into Washington's local waterways. The project includes several large-diameter conveyance and storage tunnels in the soft ground of the Coastal Plain deep under the city. Some of these new tunnels pass below existing WMATA Metro lines.

The first major tunnel construction started in 2013 and included an 8-km (5-mile) long, 7-m (23-ft) inside diameter (ID) bored tunnel along the Potomac and Anacostia rivers from DC Water's Blue Plains Advanced Waste water Treatment Plant to a pump station in the Navy Yard. Subsequent contracts included a 3.8-km (2.4-mile) long, 7-m (23-ft) ID tunnel from RFK Stadium under the WMATA Green Line and the Anacostia River to Poplar Point, and a half mile long 6-m (20-ft) ID tunnel in the Bloomingdale neighborhood along First Street (Fig. 2). All these tunnels have been successfully excavated in the Potomac Formation soils with state-of-the-art EPB TBMs. The most recent tunnel contract of the Clean Rivers Project was awarded in 2017 and will include an 8-km (5-mile) long tunnel connecting the previously constructed Anacostia River and First Street tunnels. This tunnel will also utilize an EPB TBM with pre-cast concrete gasketed segmental lining. The depth of this new tunnel system is between 21 and 49 m (70 to 160 ft) below the ground surface and includes multiple deep shafts and connection tunnels excavated by SEM. Unique to this project is the fact that DC Water used design-build procurement for all the tunnel contracts. To date, DC Water's Clean Rivers project has been successful in terms of work quality and schedule adherence. Those projects with soft-ground tunneling and design-build procurement are solid precedents for any future transit tunneling in Washington, D.C.

A final DC Water tunnel scheduled to be procured in 2020 along the Potomac River will provide additional precedent for tunnel excavation by TBM in rock, mixed-face and soil. As with the other tunnels in DC Water's Clean Rivers project, the Potomac River tunnel is expected to be procured as a design-build contract.

Current transit tunneling in other major U.S. cities

As urban areas grow in population, several major cities in the United States have been expanding their transit systems with tunneling and underground construction. These projects, which minimize impacts to surface streets and structures, are instructive in helping to envision the future of transit tunneling in Washington, D.C. As with the recent DC Water Clean Rivers tunneling program, owners in recent years have been favoring alternative delivery methods, such as design-build.

New York City

Similar to the Rosslyn Station expansion for WMATA, the New York City Metropolitan Transit Authority (NYC MTA) has added station access and increased the size of stations for a number of locations throughout their system, including Columbus Circle, Hudson Yards, Lexington Avenue/63rd Street Station, and South Ferry, just to name a few. The NYC MTA's 2015-2019 Capital Program includes $7.1 billion to expand the network through major investments. The NYC MTA receives approximately 35 percent of its income from a regional sales tax, regional tax on mortgage receipts and a tax on businesses that refine or sell petroleum-based fuel. In recent years, underground transit improvements have included:

- NYC MTA 2nd Avenue Subway (Phase 1) — $4.4 billion project includes a 3.2-km (2-mile) long segment from 96th Street to 63rd Street and includes new stations at 96th, 86th and 72nd Streets. The 2nd Avenue Subway (Phase 2), which will extend the system north to 125th Street, has started preliminary design.
- NYC MTA No. 7 Subway Extension and Station — $2.1 billion project extended the subway line from Times Square Station to the Jacob K. Javits Convention Center at Tenth Avenue and West 34th Street.
- Long Island Railroad (LIRR) East Side Access Project — $10.8 billion project, still under construction, extends LIRR service from Queens and Long Island to Grand Central Terminal.

Los Angeles, CA

The Los Angeles County Metropolitan Transportation Authority has embarked on a major expansion through Measure R, a voter-approved ballot measure that resulted in a half-cent sales tax for Los Angeles County to finance new transportation projects and programs which has been in place since 2009.

Four segments that include tunneling and underground construction are underway as design-build contracts:

- Crenshaw to Los Angeles International Airport — $1.3 billion, 13.6-km (8.5-mile) long project includes 3.2 km (2.1 miles) of tunnels and three underground stations.
- Purple Line Extension Segment 1 — $1.6 billion, 6.2-km (3.9-mile) long tunnel project includes three underground stations and extends to Beverly Hills.
- Purple Line Extension Segment 2 — $2.4 billion, 4.1-km (2.6-mile) long tunnel project includes two underground stations and extends the Purple Line to Century City.
- Regional Connector — $1.8 billion, 3-km (1.9-mile) long project through downtown L.A. will connect two existing transit lines and will include three new underground stations.

In 2016, Los Angeles County voters approved Measure M, which will provide an additional $120 billion in transportation funding over the next 40 years. With the 2028 Olympics set to be in Los Angeles, further extension of the Purple Line (Segment 3) to UCLA, the location of several sports venues are anticipated.

San Francisco, CA

San Francisco is served by both the Bay Area Rapid Transit (BART) system and the San Francisco Municipal Transportation Agency (SFMTA). Several expansion projects are underway or have been proposed.

- SFMTA Central Subway Project — $1.6 billion, 2.7-km (1.7-mile) long, tunnel project will extend the Muni Metro T-Third Street Light Rail Line from SOMA to Union Square and Chinatown. The project includes tunneling with two EPBMs and three underground stations constructed by SEM and cut-and-cover methods.
- BART 2nd Transbay Tube — this proposed project would build a second tube between Oakland and San Francisco south of and parallel to the existing immersed tube tunnel. It would connect to the new Transbay Transit Center and provide connections to Caltrain and the new California High Speed Rail.

Seattle, WA

Over the past 20 years, Sound Transit has expanded Seattle's transit system with a series of tunnel and underground projects. Since its creation in 1993, the agency has passed three major funding ballot measures. The most recent measure in 2016, Sound Transit 3, provides $53.8 billion in funding to support expansion of the transit system. The measure is partially funded by increases to sales, vehicle excise, property taxes as well as federal grants. Recent work has included:

- Northgate Link Extension — $1.9 billion project includes twin tunnels that will extend 5.8 km (3.6 miles) north from University of Washington Station at Husky Stadium.
- East Link Extension — $3.7 billion project, which includes a 610-m (2,000-ft) tunnel constructed by SEM, will extend light rail 22.5 km (14 miles) from downtown Seattle to downtown Bellevue and Redmond.

Future transit tunneling in Washington, D.C.

The future of Metro's transit tunneling in Washington, D.C. is tied to future capital investments and improvements to the Metro system. This was discussed in WMATA's Momentum Strategic Plan (2013-2025) and subsequently in planning and analyses conducted soon after the Momentum Plan for a 2040 Regional Transit System Plan. Although the 2040 Strategic Plan has not yet

FIG.3

Metro's core and core stations. Source: WMATA, Momentum, The Next Generation of Metro, Strategic Plan 2013-2025.

been finalized and adopted by Metro's Board, some of the planning associated with it has been posted on Metro's planning blog website, PlanItMetro. As highlighted by a 2013 *Washington Post* article that included an interview with Shyam Kannan, Metro's chief planner, Metro identified a need to expand capacity in the system's core to meet future transit ridership demands. This could be accomplished by adding a new core loop that includes approximately 10 new stations and adding capacity and connections at four existing stations.

This investment faces several hurdles. One of the big hurdles that Metro has faced is the lack of a local dedicated funding source, unlike many of the other cities and transit agencies previously noted. Without a dedicated funding source, it will be difficult to achieve the goals of the Momentum Plan. Now, four years since the issuance of the Momentum Plan, a local dedicated funding source was finally established in 2018 with all three jursidictions (Maryland, the District of Columbia and Virginia) committing funds. Secondly, future investment has been tied to ridership and recently transit ridership numbers have been declining across the country, especially for Metro. According to APTA, national transit ridership was down approximately 1.9 percent over the past two years. Metro's ridership has been down by 14 percent during the same period. For Metro, this is partially due to recent repair work, such as the year-long SafeTrack program, and ongoing reliability challenges. It is also due to the increasing popularity of alternative works schedules, particularly by federal workers, reductions in late-night and weekend service, as well as the popularity of Uber and other ride share companies. However, in the larger, longer view, there will be a demand for safe, efficient and reliable service that can only be achieved by new tunnels.

Additionally, the future may also include an extension of planned high speed rail by Amtrak in the Northeast Corridor south to a redeveloped Union Station, possibly extending further south to Virginia and the Southeast Corridor. Recent news reports have noted that entrepreneur Elon Musk, chief executive officer of SpaceX and Tesla, is planning to privately finance and develop a new high-speed underground transit system, Hyperloop, between Baltimore, MD and Washington, D.C. Maryland has issued a conditional utility permit to his company, The Boring Company, allowing construction of a 16.5-km (10.3-mile) section of tunnel along the proposed route. These future projects are under consideration because long tunnels and complex underground works are more feasible and can be built with less risk than in the past.

Metro

In the last two years, Metro has focused its efforts on restoring its system to try to correct years of deferred maintenance on an aging system and improving safety and reliability for the travelling public. Programs such as Back2Good, designed to get the system in good repair, and SafeTrack, an accelerated track work plan to address safety recommendations by the Federal Transit Administration and the National Transportation Safety Board, have been implemented. Through SafeTrack, Metro completed approximately three years' worth of maintenance and repair work in approximately one year. Much of the system's maintenance work is related to leaking tunnels constructed in the 1970s and 1980s. Today's tunneling industry has the ability and technology to construct nearly watertight tunnels, representing a huge improvement over past construction methods.

The Momentum Plan identified several key issues, which are common to other major cities in the United States that have invested in transit improvements:

- Improve regional mobility and connect communities.
- Enhance access.
- Add operational redundancy.
- Build for the future.
- Add new sources of predictable funding.

As noted in the Momentum Plan, the region is forecasted to increase 30 percent in population and 39 percent in employment over the next 30 years. And Washington, D.C. is one of the few metropolitan areas where growth is occurring in the city core, inner suburbs and outer suburbs. The Momentum Plan identified core station improvements, including pedestrian underground

connections, that Metro stated should be completed by 2025 to have maximum impact, increase system and core capacity, and improve the effectiveness of the rail network. These improvements are envisioned at stations such as Metro Center, Gallery Place, Union Station, L'Enfant Plaza, Farragut West, and Farragut North (Fig. 3). In 2012 dollars, they were estimated to have an order of magnitude cost of $1 billion.

Other conceptual improvements, included in the Momentum Plan, were further evaluated by Metro during the planning effort for a 2040 Regional Transit System Plan. These improvements would be required, in addition to the 2025 Plan Core Station Improvements, to serve the region's transit needs with the projected growth. It noted that as transit patronage reaches full capacity on lines converging at Rosslyn and L'Enfant Plaza Stations, new east-west and north-south transit tunnels through Arlington and Washington, D.C. would be required to accommodate trips and improve capacity through the system core. Some of those improvements, with associated order of magnitude cost in 2012 dollars, related to future transit tunneling include:

- New connection of existing lines at the Pentagon with a new Pentagon Station ($600 million).
- Silver/Orange Line Express Line from West Falls Church to a 2nd Rosslyn Station to a relocated Blue Line ($2.3 billion) — this would allow passengers on the Silver and Orange Lines better access to the eastern side of downtown Washington. A second Pentagon station would allow passengers on the Orange and Silver lines to reach the Pentagon without having to switch to the Blue Line. The underground portion of this new line would begin in the Piedmont bedrock at the Rosslyn Station and then transition to Coastal Plain soil deposits at the second Pentagon Station. Tunneling could be completed by an EPB TBM or a Hybrid TBM (Fig. 4).
- Relocated Yellow Line ($2.7 billion) — this would improve north-south capacity and require a new tunnel south from the Pentagon under 10th Street SW and NW and then west to Thomas Circle allowing the Green and Yellow lines to operate in separate tunnels. As this alignment is generally in the Coastal Plain Deposits, tunneling could be accomplished using either a Slurry or EPB TBM.
- Relocated Blue Line ($3.3 billion) — this would improve east-west capacity by creating a new Blue Line alignment through Rosslyn to Georgetown and then along M Street NW to Thomas Circle. As this alignment is primarily in the Piedmont sections of Washington, D.C., tunneling could be accomplished using a hard rock TBM. Station construction could be completed fully by SEM or cut-and-cover methods. Construction of a station in Georgetown could be completed by SEM construction with significant attention made to protect existing

FIG.4

Conceptual new Metrorail Blue Line connections at Rosslyn Station. Source: WMATA, Momentum, The Next Generation of Metro, Strategic Plan 2013-2025.

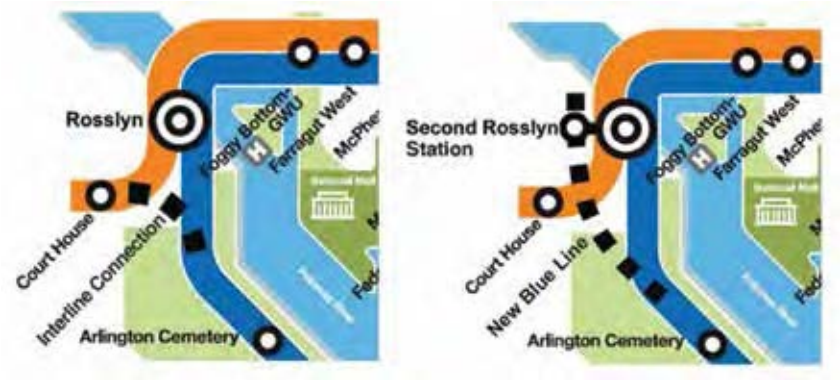


FIG.5

Proposed 2040 Metrorail network – Core Loop. Source: WMATA Planning Website and Blog. https://planitmetro.com/.

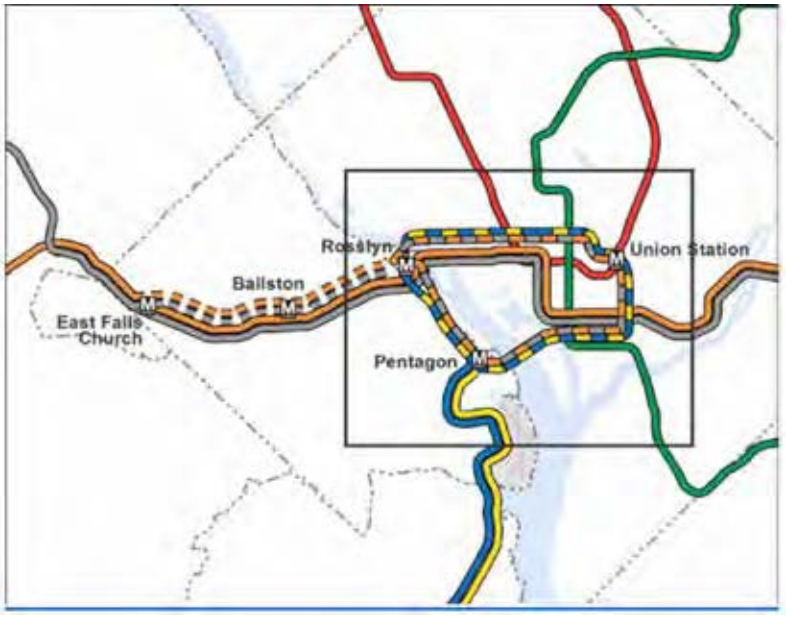
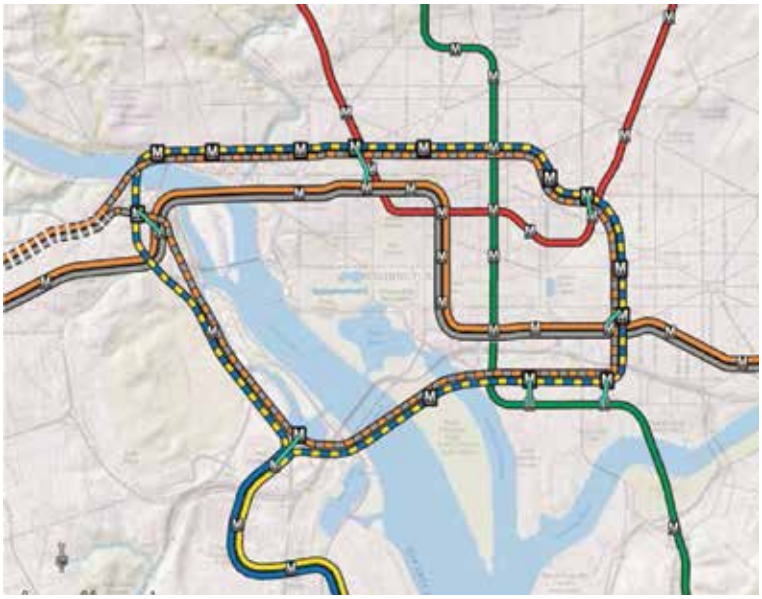


FIG.6

Proposed 2040 Metrorail network – Core Loop detail. Source: WMATA.



structures through a congested part of the city with the use of ground improvement.

As indicated on the PlanItMetro website, one possible way to increase capacity in the downtown core would be the conceptual development of a Core Loop (Figs. 5 and 6) that extends north from a second Rosslyn Station in a deep tunnel to Georgetown, extends east toward Union Station to a second Metro station at Union Station

FIG.7

Conceptual proposed WMATA Metrorail line south of Union Station. Source: U.S. DOT Federal Railroad Administration (FRA), 2017, Washington Union Station Expansion Project, Concept Screening Report.

possibly constructed below the existing station while providing connections to the existing Red and Green Lines along the way. As shown in the conceptual figure, the Core Loop could then extend south and west to address the needs from the Relocated Yellow Line noted in Momentum. This work would involve tunneling and underground construction for the stations. These are conceptual drawings and future planning could lead to alternatives such as a continuation of the new line from Union Station to the east, perhaps 3.2 km (2 miles) to RFK Stadium.

Union Station redevelopment

The Union Station Redevelopment Corporation (USRC), in coordination with Amtrak, is planning for a $7-billion phased expansion and modernization of Washington Union Station. The historic station, which opened in 1907, is proposed to handle triple the number of passengers and double the train service. Major improvements are being planned to add a 3-million SF air-rights development, named Burnham Place after Union Station architect Daniel Burnham, over the train shed. Additional improvements include increasing capacity along the Northeast Corridor to New York and Boston with the addition of new underground passenger concourses below the existing train shed, and plan for possible High Speed Rail, extension of Maryland Regional Rail Trains to Virginia, as well as possible extension of Virginia Railway Express trains to Maryland.

Constructed in the 1970s, Metro's busiest station is at Union Station on the Red Line. The near-term station access improvements planned by Metro will be included in the Union Station redevelopment. According to the U.S. DOT Federal Railroad Administration (FRA) 2017 Concept Screening Report, a second Metro Line servicing Union Station is being considered in long-term planning (beyond 2040) in order to meet future travel demand. The proposed conceptual alignment is parallel and south of Massachusetts Avenue passing along the southern edge of Columbus Plaza, directly south of Union Station (Figs. 7 and 8). A second Metro Station would need to be constructed below the existing station at Union Station. This station would extend roughly between North Capitol Street and Louisiana Avenue, below existing surface parking lots just south of Massachusetts Avenue. Tunneling using a Slurry or EPB TBM would likely be required, combined with SEM for station construction within the Coastal Plain deposits. Alternatively, the second Metro Line could be located on the north side of Union Station to tie-in with the planned air-rights development. This would allow Union Station to be served by two Metro Lines. However,

the new Metro station would not be a transfer station due to the distance from the existing Metro Station on the Red Line.

High speed rail

High speed rail (HSR) connecting to the Northeast Corridor, which is only being considered in the fourth phase of Union Station Redevelopment, would likely enter the station at a new deep underground level below the existing station and platforms. High speed rail tunnels entering Union Station from the north would likely need to begin somewhere around the Anacostia River crossing, approximately five miles north of the station. As the tunnels enter the station, they would need to be aligned in coordination with the existing large footings which are supporting the existing historic station structure on Coastal Plain Terrace Deposits. For HSR to continue south to Virginia, it is possible that twin-bored tunnels would follow an arc route out of the station and below the National Mall before crossing the Potomac River into Virginia. The FRA, in cooperation with the Virginia Department of Rail and Public Transportation, is preparing a Tier II environmental impact statement for the 198-km (123-mile) portion of the Southeast High Speed Rail Corridor from Washington, D.C. to Richmond, VA. The study begins at the southern terminus of the Long Bridge across the Potomac River in Arlington, VA.

Due to the shallow connection at Union Station, it is anticipated that twin-bore tunnels would be a preferred approach, rather than a single large-bored tunnel with two tracks which would require more complex underpinning. Due to high groundwater levels and Coastal Plain deposits, a pressurized-face TBM, either slurry or EPB, would likely be used to build the HSR alignment south of Union Station. A superconducting maglev program to provide a high-speed connection in tunnels between Baltimore and Washington, DC is also being considered by planners.

FIG.8

Conceptual future WMATA Metrorail line and station south of Union Station. Source: U.S. DOT Federal Railroad Administration (FRA), 2017, Washington Union Station Expansion Project, Concept Screening Report.

Conclusion

Washington, D.C. expects an increase in population, employment and transit oriented development over the next 30 years that will put a strain on the existing Metro transit system. This led WMATA to develop the Momentum Strategic Plan 2013-2025 that identified core station improvements, new east-west and north-south transit lines that would improve access and effectiveness of the network in the system core. These proposed improvements, amounting to more than $10 billion (in 2012 dollars), would require tunneling and underground structures. In addition, Washington Union Station is about to begin a $7 billion phased expansion and modernization program that will include significant underground construction at the station and may include tunneling for High Speed Rail from the Northeast Corridor, through Union Station and south to Virginia across the Potomac River. These future projects are under consideration because long tunnels and complex underground works are more feasible and can be built with less risk than in the past.

Having a reliable funding source with dedicated funding from the region for the first time ever is a big step for the Washington Metro to meet its future needs. Other major cities such as New York, Los Angeles, Seattle and San Francisco have addressed the funding hurdle for transit capital programs, together with federal support, and are underway with major tunneling and underground construction works. A recent decline in transit ridership, particularly in Washington, D.C., would need to demonstrate signs of recovery before decision makers would be willing to make the substantial investments required to improve the transit system. However, planning and conceptual design work should continue given the clearly identified future demand in the system core. State-of-the-art tunneling and underground construction methods that have been used in other major cities for recent transit tunneling projects have been successfully used in Washington, D.C. for recent Metro expansion as well as the DC Water Clean Rivers Program. Therefore, Washington, D.C. is poised for significant transit tunneling work in the future. (References available from the authors.) ■

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FEATURE ARTICLE

Rehabilitation of tunnels: An owner's perspective

Since ancient times, storing and conveying water via underground water systems and tunnels has been touted for its strategic advantages. Underground cisterns and tunnels assured protection of essential fresh water supplies from man made contamination and especially from enemies who would gain an advantage by disrupting an adversary's water supply in a siege. Modern-day engineers do not usually specify tunnels for reasons of avoiding deliberate contamination or siege — however, they are just as enamored with the idea of building tunnels for water conveyances.

Such was the case for the San Francisco Public Utilities Commission (SFPUC). The SFPUC provides drinking water to 2.6 million residential, commercial and industrial customers in the San Francisco Bay Area. The SFPUC's water system includes 257 km (160 miles) of transmission pipelines and tunnels from the SFPUC's largest reservoir, the Hetch Hetchy Reservoir inside Yosemite National Park, to San Francisco. About 129 km (80 miles) of the system consist of tunnels. A 30-km (19-mile) section of the tunnel network, called the Mountain Tunnel, was thought to be at risk of a catastrophic failure in its concrete-lined section of 18 km (11 miles). For much of the project planning process, a new replacement tunnel was presumed to be required according to the tunnel planners.

Originally constructed between 1917 and 1925, the Mountain Tunnel has been in continuous service since 1925. The 30-km (19-mile) tunnel is located downstream of the Hetch Hetchy Reservoir water source in Yosemite National Park, between the Early Intake and Priest Reservoir (Fig. 1). Approximately 18 km (11 miles) of the tunnel is lined with unreinforced concrete. Though the condition of the tunnel was being monitored through water sampling and periodic inspections, there was growing concern that the tunnel lining was at risk of a partial collapse that could interrupt water delivery for up to nine months. The SFPUC was faced with a decision to construct a new bypass tunnel to replace the lined section of the Mountain Tunnel or to rehabilitate the existing tunnel.

David Tsztoo, Anthony Yu and Teena Redhorse

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In order to decide between constructing a new tunnel or rehabilitating the existing one, the SFPUC embarked on a detailed alternatives analysis study, developing a set of performance standards for the tunnel, and identifying different alternatives. The study included four alternatives for in-depth review (McMillen Jacobs, 2017):

- Rehabilitate the existing tunnel, focusing on repair and contact grouting of the 18 km (11 miles) of concrete lined section.
- Relining with smaller-diameter steel pipe in the 18 km (11 miles) of the concrete-lined section.
- Construct a new bypass tunnel within the tunnel right of way to replace the 18 km (11 miles) of concrete lined section.
- Construct a new bypass tunnel outside the tunnel right of way to replace the 18 km (11 miles) of concrete lined section.

A 60-day shutdown of the tunnel was scheduled in early 2017 to perform a visual inspection, gather detailed information regarding the location and type of defects in the lining and establish the current structural condition of the tunnel (Fig. 2). The inspection indicated the many defects in the existing tunnel lining and the feasibility of repair (McMillen Jacobs, 2017).

The study also performed geotechnical investigations to ascertain site conditions for the new tunnel alignments, a condition assessment of the existing tunnel and a detailed hydraulic analysis to assess the flow capacity of the existing tunnel and evaluate effects of various improvements. The overall assessment was that existing tunnel was found to be not beyond repair and many sections to be in relatively good condition (McMillen Jacobs, 2017). The hydraulic analysis indicated that relining the tunnel would significantly reduce hydraulic capacity (McMillen Jacobs and Black & Veatch, 2017). So, the selection of the preferred project came down to comparing the rehabilitation and the new bypass tunnels against the performance standards and the other considerations of construction, environmental, permitting, cost and schedule described in this article. After thoroughly reviewing all this information and data at hand, the SFPUC ultimately decided the best course of action was to rehabilitate the Mountain Tunnel.

Why rehab?

The purpose of this article is to explain why tunnel rehabilitation can sometimes meet the needs of water

FIG.1

Mountain Tunnel is downstream of Hetch Hetchy Reservoir. Source: SFPUC 2017.

agency owners better, or just as well, as new tunnels or bypass tunnel projects. Many owners are resource limited. They have competing program priorities, limited capital resources and limited staff expertise to undertake and properly manage mega size new tunnel projects.

Water agency capital budgets typically include many improvement projects competing for the same capital. The project list can include improvements to treatment facilities, transmission pipelines, pump stations and other facilities besides tunnel projects. Not every project gets immediately funded and some are postponed for later funding in a 10-year plan. Owners want to stretch every dollar to cover as many priority projects as possible.

Water agency owners typically have to sell bonds to fund their capital projects. The sale of bonds is a long-term financial commitment that many water districts are more hesitant to undertake

FIG.2

Cataloging every lining defect during the 2017 tunnel inspection. Source: Robin Scheswohl/SFPUC 2017.

FIG.3

Cleaning the lining defect to exposed rock and reinforcing with wire mesh prior to shotcrete. Source: SFPUC 2017.

in fiscally conservative times. Smaller water districts, in particular, are not willing to mortgage the future operations of the district to significant long-term debt.

Some districts have to also contend with stakeholder and customer opposition to the raising of water rates to service the debt payback. After years of increased water rates to pay for improvements on other parts of the SFPUC water delivery system, ratepayers would be understandably wary of additional increases to their water bill to pay for a new Mountain Tunnel.

It's about less money and time

When choosing to upgrade major transmission facilities, most water districts would look seriously at cheaper alternatives rather than undertake a total replacement facility. Most owners would want to avoid a situation where the entire program budget is dominated by mega size projects, with outsized impacts on annual cash flows to service bond debt and unpopular customer rate increases to cover the bond repayments — as may be the case of large capital improvement programs, including new, expensive tunnel projects.

Given a choice between constructing a new tunnel, or bypass tunnel, or simply a rehabilitation of the existing tunnel, owners would naturally first look at the rehab option. Rehab projects are significantly cheaper than building from new. It is estimated that the upfront capital outlay of a rehab can be 30 percent to 50 percent of the cost of comparable size and length of a new or bypass tunnel. Cheaper upfront capital investment in initial construction can mean increased financial capacity to invest in periodic maintenance of a rehabilitated asset for the long term.

Because the scope of work for a rehab is significantly less, the rehab may be completed in approximately half the time or significantly less time for comparable size facilities. This also translates to significantly less expense for project management and other soft costs. A relatively simple rehab project will not require large consultant services contracts for highly skilled and expensive design consultants. Nor would just-as-expensive construction managers and inspectors need to be hired on large, multi-year contracts to do contract administration and in-tunnel inspections.

There is significantly less cost and schedule associated with property acquisition for a rehab project. No permanent tunnel easements or rights of ways are needed for new tunnel alignment. Permitting for temporary construction surface access and staging areas for non-agency owned property takes less effort because either the rehab project does not requires them or require less of them. In the case of the new tunnel alignment proposed for Mountain Tunnel outside the tunnel right of way, there was the need to acquire tunnel easements and temporary surface rights for staging and access through private property and national forest lands. The property issues included concerns about noncooperative private owners, working with the U.S. Department of the Interior, and possibly with U.S. Congress for the final approval — a potentially long and daunting process.

Rehab projects can be done without the need for subsurface exploration. A new tunnel by comparison must conduct an extensive geotechnical investigation along any new alignment, at locations where tunnel portals, adit tunnels and vertical shafts are contemplated for the design. All this is dependent on gaining temporary access usually through private or other agency-owned property. The longer the new alignment, the more complicated and time-consuming will be the effort. All such considerations are essentially cost and time savings for owners who elect to go with the rehab option.

Construction considerations

With any new tunnel, there is also an increased risk of cost overruns due to technical challenges, unforeseen conditions, large upfront costs for tunnel boring machines

and other support equipment, constraints on the electrical grid for construction power, and environmental unknowns. Each new day of new tunnel excavation can yield a new set of unknowns and the potential differing site condition change order.

By contrast, tunnel rehab projects are somewhat repetitive and have fewer unknowns that could promote a lot of cost overruns. The tunnel repairs are typically classified into about four types ranging from patching of small holes to routing, cleaning and backfilling of much larger cavities with welded wire mesh and shotcrete (Fig. 3). The design details and the construction for these repairs are fairly similar from rehab to rehab project. It is fairly easy for contractor labor crews to get proficient after the first few repairs of each type of repair, gain efficiencies from lessons learned, and possibly make remarkable reductions in the unit cost and unit time of the repairs. This would make subsequent repairs of the tunnel more efficient and less likely to overrun.

The scope of a rehab project also lends itself to flexibility during construction. Tunnel rehab construction focuses primarily on repair of the concrete lining. Such repairs are discrete as opposed to continuous construction along the tunnel alignment that must be completed in blocks or sections before any return to service can be contemplated. Discrete repairs can be done in prioritized batches, or as much as the owner's shutdown window constraints and budget allows.

Politics of new versus old

Sometimes, project leadership has been known to advocate for new replacement projects for reasons other than the practicality of cost and time, or even beyond the performance standards. New projects promise improvements that can be considered as a panacea for problems ranging from the old facility as allegedly beyond repair, to local hiring for a massive number of construction jobs, to having the opportunity to associate one's name with a legacy project.

By contrast, there is less glamor and notoriety associated with a repair or rehab project. Tunnel rehab projects tend to be very similar and familiar. The main work is the patching or repair of various defects ranging from small holes to larger sections big enough for an inspector to crawl into. The repair is usually performed by shotcreting followed by systematic contact grouting through injection holes drilled through the repaired sections and into the native rock surrounding the tunnel in order to fill the annular spaces between the rock and the lining. In the case of the current SFPUC Mountain Tunnel, the repair details are almost a carbon copy of similar repair details developed 15 years ago for the East Bay Municipal Utility District's Claremont Tunnel.

Environmental considerations

New tunnel projects generally must undergo an extensive environmental review process before the project can be approved for construction. For projects in California, this involves the development, internal reviews and public review process of an environmental impact report (EIR) over several years. If a federal agency is involved as a project participant or for the approval of property for the tunnel easements and temporary construction staging areas, then an environmental impact statement (EIS) is also required. The EIS can be done concurrently with the EIR, but is typically completed with lag of an additional six months to more than one year after the EIR certification to allow the findings and related information in the EIR to be re-used in the EIS.

The environmental impacts of new tunnels are generally unavoidable and beyond simple mitigation offsets that are easily accepted by the communities that must host the construction of the tunnel facilities and staging areas. Neighborhoods must endure the visibility, dust and noise and share the streets and highways with the hundreds of truck traffic on a daily or weekly basis over many years of construction, and may want more mitigation for their endurance.

New tunnel construction projects of large diameter and long alignment have the additional issue of dealing with exceedingly large volumes of tunnel spoils. Such spoils must be transported often at long distances to commercial disposal fill sites, or shorter distances to agency owned fill sites. The longer haul to commercial sites often involves disclosure of the volume of regulated diesel emissions that have health effects on the public. The shorter haul to agency owned sites may involve less diesel emissions but requirements on the back end of the project for site restoration and native plant re-establishment.

Rehab projects generally have little to no significant environmental impacts that must be described, mitigated and publicly vetted before the project can be approved for implementation. Repairs, contact grouting and other work to rehab or improve an existing tunnel are completed underground and with relatively little surface visualization. The standard construction impacts of noise, traffic and environmental pollution can be avoided or mitigated by design to the point of insignificance. Rehab projects typically require smaller surface areas for temporary staging of construction trailers, equipment parking and storage of materials.

The environmental review process for a rehab project typically involves less documentation and less public review. Because the environmental impacts are so much less or can be avoided, it is often possible to publish a mitigated negative declaration for the rehab project. If federal agencies are involved, the comparable federal document is the environmental assessment. Both documents are easier and less time consuming to develop and may save about one year compared to the EIR/EIS process for the new tunnel (AECOM, 2017).

Environmental permits

Separate from the environmental documentation

FIG.4

Repairing the lining defect with shotcrete. Source: SFPUC 2017.

process is the issue of obtaining the environmental permits to allow construction to proceed. For example, in California, a biological opinion must be evaluated and obtained, and then California Department of Fish & Wildlife permits must be obtained. If the project involves federal participation or obtaining of easements, then U.S. Fish & Wildlife Service permits must be obtained. Such permits typically require special expertise either in-house or hired as consultants to interact with the permitting officials in order to work out conditions of approvals and details of the final project descriptions before the permit can be approved. It is not uncommon for such permits to consume more than a year of critical schedule after the environmental review process is completed.

If the project requires new tunnel easements and temporary surface easements for staging areas in national park land or forest preserves, as was the case for the new Mountain Tunnel options, then the permitting process is more complicated. The federal agency may pre-condition the granting of property easements on the approvals of the environmental review process, and in the process add more conditions of approval to the environmental permits.

Meeting performance standards

It is generally assumed that new tunnel projects can be designed to satisfy any set of performance standards for the project. While this is basically true, it overshadows the fact the most performance standards are derived from the design and operations of the existing facility, with perhaps a few upgrades.

In the case of the SFPUC Mountain Tunnel Improvement project, some of the performance standards were based upon the performance of the existing tunnel back when the tunnel was relatively new. A few standards were derived from the current operations of the tunnel. There were eight performance standards used as criteria for the selection of the preferred project during the project alternatives analysis (McMillen Jacobs, 2017):

- Service life: This standard requires the typical tunnel design for 100 years of service life. Although the best way to meet this standard is to construct a new tunnel, the rehab option can also achieve a 100-year service life. The Mountain Tunnel design consultant's solution was to fix all the defects in the concrete lining with welded wire reinforcement and shotcrete and perform contact grouting to fill all the annular spaces between the lining and the surrounding rock (Fig. 4). When completed, the lining should be as structurally sound as a new lining and the rehab tunnel should last another 100 years with normal, periodic maintenance.
- Water quality: This standard limits the overall turbidity from Mountain Tunnel to occurrences of more than 1 NTU to no more than twice per year, and occurrences of more than 100 NTU to no more than once every five years. During normal operations, ground water intrusion is the main culprit for degrading water quality. For both new and existing tunnels, a way has to be found to limit this intrusion. For concrete tunnels, the best way to cut off the intrusion seepage pathways is to do an adequate job of grout injection of the native ground surrounding the tunnel, or contact grouting. For the rehab project, the entire 18 km (11 miles) of concrete-lined section will be aggressively contact grouted, essentially sealing the rehab tunnel from seepage.

As an improvement, Mountain Tunnel will also install new large control valves at the downstream portal to keep the tunnel full of water when the tunnel is not running. With the tunnel full and pressurized, there would be little to no hydraulic gradient for the initiation of ground water intrusion. In addition, a short section of very leaky tunnel, upstream of the South Fork Siphon crossing underneath the Tuolumne River, will be replaced by a new 137-m (450-ft) long bypass tunnel section. This will eliminate the one worst section where ground water intrusion occurs the most.

- Water conveyance capacity: This standard requires a hydraulic capacity of 740 cfs (478 MGD). Advantage goes here to a new tunnel, in that a new tunnel can be sized to accommodate any flow capacity. However, in the case of the Mountain Tunnel rehab, flow capacity will be enhanced by the complete repair of wall defects, and invert paving and possibly smoothing, to improve hydraulic efficiency. The rehab project should be able to recover 706 cfs of initial capacity, or more than 95 percent of this performance standard. The SFPUC found this sufficient and efficient when the consideration of budget cost and schedule savings over the new tunnel are factored in. Also, the addition of downstream control valves to keep the tunnel flow at full volume will eliminate the erosive effects of the current tunnel operations, with intermittent surges and turbulent transitions between full flow and open channel flow inside the tunnel on a daily basis.
- Minimum flow: This standard requires a minimum flow rate of 300 MGD be available at all times outside of planned and unplanned outages. This is actually a fairly easy criterion to satisfy for a new tunnel and a rehab tunnel. For an existing tunnel, the key is to do the repairs of lining defects competently so that lining fallout does not occur and block flow capacity. This is accomplished by routing the defects back to structurally sound concrete, and backfilling the cavity with welded steel reinforcement and high strength shotcrete. The resulting repair would be as structurally sound as new lining.
- Operational flexibility: This standard includes four key operations. Mountain Tunnel must accommodate reductions in demand such that the tunnel may operate in open channel flow for extended periods. The tunnel needs to operate at full portion to meet water supply needs. The tunnel needs to accommodate power generation and local recreational needs, such that the tunnel may operate with substantial fluctuations in daily and hourly flows to the extent possible. The tunnel needs to accommodate full dewatering every five years for 100-day shutdowns for needed inspections of the Hetch Hetchy Aqueduct. The new tunnel and rehab tunnel can both be designed to handle all of these operational needs. In the case of the Mountain Tunnel rehab, downstream control valves will be added to maintain full volume flows so the erosive effects between full flow and open channel flows can be significantly avoided. With the downstream control valves, keeping the tunnel full of water, flows can be ramped up and down relatively quickly without developing the vacuum or surge pressures that promote erosion of the lining.

  A related operational consideration during construction is the owner's requirement for emergency return to service. The implementation of tunnel repairs can be done in finite prioritized batches. Such repairs are discrete as opposed to continuous construction along the tunnel alignment that must be completed in large units before any return to service can be contemplated. This is a very important consideration for any owner that encounters an event that requires an emergency return to service. Such emergencies usually require the curtailing of construction and return to water services over a few days. The 2017 Mountain Tunnel inspection and interim repair contract had a three-day requirement for the contractor to return the tunnel back to the owner for emergency return to service.
- Planned outages: This standard requires the reliable operation of the tunnel with an inspection frequency of 20 years with outage durations limited to 30 days, and major repairs at no more than once every 20 years with outage durations limited to 100 days. This is fairly easy for a new tunnel or a rehab tunnel to satisfy. After completion of both types of projects, the key is to not ignore the periodic maintenance required to keep the tunnel lining in good physical condition, and eliminate the need for major maintenance that often results from neglect. In the case of the rehab tunnel, the repairs need to done competently so that lining fallout does not occur and require major maintenance.
  For Mountain Tunnel, simple planned inspections would only require outage durations of less than 10 days. A 30-day outage would allow time for some patchwork repairs of the lining. These short duration outages should be conducted concurrently with the five-year periodic outages for the Hetch Hetchy Aqueduct inspection interval under the operational flexibility performance standard. Periodic inspections every 20 years with outage durations of 100 days for the Mountain Tunnel should only be planned if major repairs are needed. Again, the goal of the inspection outages should be to catch the incipit defects when such defects are still small in size and fairly easy to repair.
- Unplanned outages: This standard limits the interruption in water delivery from a catastrophic event to no more than 90 days. Although there is uncertainty with any catastrophic event, the new tunnel and rehab tunnel can both be designed to make the lining as robust as possible to withstand shakeout from the forces of remote earthquake faults, or inadvertent damage from man-made events. Such is the case with the Mountain Tunnel rehab. The 2017 inspection found the existing

tunnel lining to be an average of 35 cm (14 in.) thick. The rehab will structurally repair all the defects and the entire 18 km (11 miles) of lined section will be contact grouted to make sure the lining is in intimate contact with the surrounding granitic rock. By doing so, any need for repairs after a catastrophic event will be mitigated and the forecast interruption for repairs should be less than 90 days.

- Seismic reliability: This standard requires the reliable delivery of the minimum flow without interruption following a near tunnel seismic event. This is the easiest of the performance standards to satisfy in that the tunnel does not cross any active earthquake faults and the Sierra foothills location of the tunnel is in a region of low seismic activity.

Recommended inspections and maintenance

Comprehensive and competent repairs and contact grouting during the rehab construction should produce a tunnel whose lining is free from defects and with a renewed service life that compares with a new tunnel lining. It is important for owners to support the renewed tunnel with proper, periodic inspection monitoring, water quality testing and maintenance. The inspection should be conducted at reoccurring intervals of between five and 20 years, as required by tunnel condition. The inspections may have to be conducted at shorter intervals if it is noted during the initial inspection that the erosion is occurring more aggressively than anticipated. The key is to catch any new defects in the lining while they are still incipiently developing. Such defects should be small in scope and more easily addressed in subsequently scheduled tunnel shutdowns that are well planned and budgeted in advance. If the repairs can be scheduled periodically at intervals of no more than 20 years or concurrent with the inspections, then the scope of repairs will be less significant, cost less per shutdown, and be able to be accomplished in fewer shutdowns of shorter duration, with better control of the scheduling and costs of the work—all good considerations for budget and operation minded owners.

Conclusion

Done right, the rehab tunnel project can result in a renewed tunnel that can match the 100-year service life and other performance standards of a new tunnel but at a fraction of the cost and schedule. The new tunnel can be a more glamorous project to design and construct, but the renewed tunnel will typically require a less complicated and time-consuming environmental review process and fewer environmental permit conditions for completion. In the case of Mountain Tunnel, the rehab project can almost match the required flow capacity of the new tunnel with the same accommodations for operational flexibility, planned and unplanned outages, and seismic reliability. As with any new or renewed tunnel, the key to facility longevity, without major headaches, is the attention and commitment to performing periodic inspection and maintenance. A well-designed and executed periodic repair program with the newest engineering and construction methods can yield similar results in a fiscally responsible way. The rehab option will successfully preserve the SFPUC's Mountain Tunnel and meet its needs for many years to come. ■

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Atlanta, GA

2019 Fox Conference
January 29, 2019
Graduate Center, City University of New York,
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FEATURE ARTICLE

Use of innovative techniques and tools on a massive tunnel project

There's no fast way to add more than four miles of track, most of it underground, to the Sound Transit Link Light Rail system in the Seattle area. But increasingly busy traffic through a number of neighborhoods made it necessary. That's the challenge a joint venture of several tunneling contractors faced when starting its portion of the $1.9 billion Northgate Link Extension in 2013, and the project is still keeping them busy three years later. Completion will mean just a 14-minute ride from Northgate to downtown for an extra 60,000 passengers by 2030. The transit lines will join 58 km (36 miles) of new and under-construction light rail lines running north, east and south from Seattle.

Voters, tired of long commute times, approved the project, a key part of Seattle's regional mass transit system, in 2008. The extension is part of a plan adopted by the Sound Transit board in 1996 to connect the region's major activity centers. The Northgate project is meant to relieve one of the area's most congested traffic areas by connecting the Northgate, Roosevelt and University District neighborhoods to existing routes including downtown Seattle and SeaTac airport.

Sound Transit dedicated more than a quarter of the project's estimated expense — $440 million -— to general contractor JCM Northlink LLC to handle the tunnel segment. JCM is a joint venture formed in 2013 between Jay Dee Contractors of Livonia, MI, Frank Coluccio Construction of Seattle, WA and Michels Corp. of Brownsville, WI. The contractors regularly collaborate on large-scale projects and brought experience working on a different section of the extension they completed in 2013.

JCM project leaders knew immediately that the schedule would be demanding. They had to work around the clock, six days a week to meet deadlines. The extension runs through highly populated areas, meaning contractors had to follow strict city noise restrictions between 10 p.m. and 7 a.m. Plus, supervisors needed to manage the scheduling of nearly 250 employees to keep work running smoothly.

"We had eight different operations and four different subcontractors trying to work in one tunnel," said Chris Wood, JCM site project superintendent. "It's important that we keep work linear. That's the biggest challenge: keeping a path in and out so you can pour concrete, keep electricians and carpenters going, and accomplish everything else."

Project planners also realized they wouldn't be able to use the same equipment they had in the past for tunneling projects. The tunnels would run directly below the University of Washington, which has long-standing, ongoing sensitive science projects. The train and tracks JCM used for past projects to transport crews and supplies through tunnels are loud and produce significant vibrations, which would have disrupted the experiments. To lower noise levels throughout the tunnel and to avoid disturbing the university, project leaders incorporated new sound abatement methods. JCM brought in seven Metalliance rubber-tired vehicles that stretched 16 m (52 ft) long but were just 2 m (6 ft) wide and could handle 41 t (45 st). Crews could use them as an alternative to a locomotive on rail for transportation in and out of the tunnel. In addition, the vehicles work with a number of attachments, including high-car platforms and concrete distribution attachments, reducing the need for additional equipment.

Workers use a Brokk 400D with a TEI 350 rock drill to drill through a tunnel wall. Crews used the attachment to drill holes for steel spiles, well points and freeze pipes.

Crews started the tunneling portion of the project by digging two large vertical shafts and a tunnel portal to initially be used as access points for tunnel boring machines (TBMs), service work, material removal and supplies. The shafts will be converted to light rail stations when the project is complete. JCM used a Kroll 15000 tower crane with 4,900 kg (108,000 lbs) of lifting capacity, the third largest capacity in North America, to lift stacks of tunnel liner segments, equipment and material in and out of the 31-m (100-ft) deep shafts.

Once shaft construction was well underway, JCM began digging the twin-bore tunnels from Northgate to the already-excavated University of Washington station and existing light rail track. Crews used Hitachi Zosen (Hitz) and Robbins TBMs to simultaneously dig two parallel 7-m (21-ft) diameter tunnels. The machines stretch about 122 m (400 ft) long and advanced an average of 9-15 m/d (30-50 ft/day).

The tough soil didn't make the job easy. The TBMs hit harder ground than anticipated, slowing down the machines as cutters and scraper heads wore down or broke against

JCM crew members stand in front of one of the tunnel boring machines as it sits idle. Crews used Hitachi Zosen (Hitz) and Robbins TBMs simultaneously.

cobbles and boulders.

As tunneling moved along, crews started digging 23 cross passages between the tunnels. The 5- to 6-m (16- to 20-ft) long openings house electrical rooms and serve as safe havens and escape routes for train passengers in case of an emergency.

Cross passages are typically constructed using pneumatic tools and mini-excavators, but about five years ago, on another section of the light rail expansion, JCM began using a different approach: Brokk remote-controlled demolition machines. They made the switch to limit worker exposure to harsh tunnel environments and reduce the inevitable fatigue and potential injuries that come with using handheld tools all day. The remote-controlled technology also allows workers to operate the units from a safe distance, minimizing exposure to falling debris. JCM owned a Brokk 260 from an earlier project but with the increased demands and tight deadlines of the Northgate project, they decided to invest in two larger Brokk 400Ds and rented another in order to maximize productivity. The equipment's efficiency and precision sped up the excavation portion to less than three weeks, shaving off more than a week of work compared to handheld tools. In addition, the machines held up well in tough tunneling conditions.

"I tell everybody that anything that goes down into that tunnel will get broken. I can give these guys a glass of water and somehow they'll break the water," Wood said. "But the Brokk remote-controlled machines withstand the conditions. When we do have issues, Brokk field mechanics work with our mechanics to limit detrimental downtime by bringing in parts and fixing the unit right away."

JCM worked on multiple cross passages at a time. Crews typically started the passages by pairing the Brokk 400D with a TEI 350 rock drill attachment drilling 10-cm (4-in.) diameter holes for well points and 6-m (20-ft) steel spiles. These were installed about every foot to create a canopy to secure the ground and protect workers from falling debris. Once the spile canopy was completed, JCM needed the maneuverability and compact size of the Brokk 260 paired with an Atlas Copco SB 302 hydraulic breaker to break through the tunnel wall. After getting through the concrete, JCM brought back the B400D to complete the passage, often alternating between an Atlas Copco SB 552 hammer to break through the ground and a Simex road header to mill the walls. Workers used mini excavators to remove material and load it into dump trucks, and crews coated the walls with shotcrete to keep them in place. Each passage took seven to nine weeks to complete, including waterproofing, installing rebar, pouring the invert and headwalls, and finalizing 82 to 100 m (90 to 110 yd) of fiber-reinforced concrete.

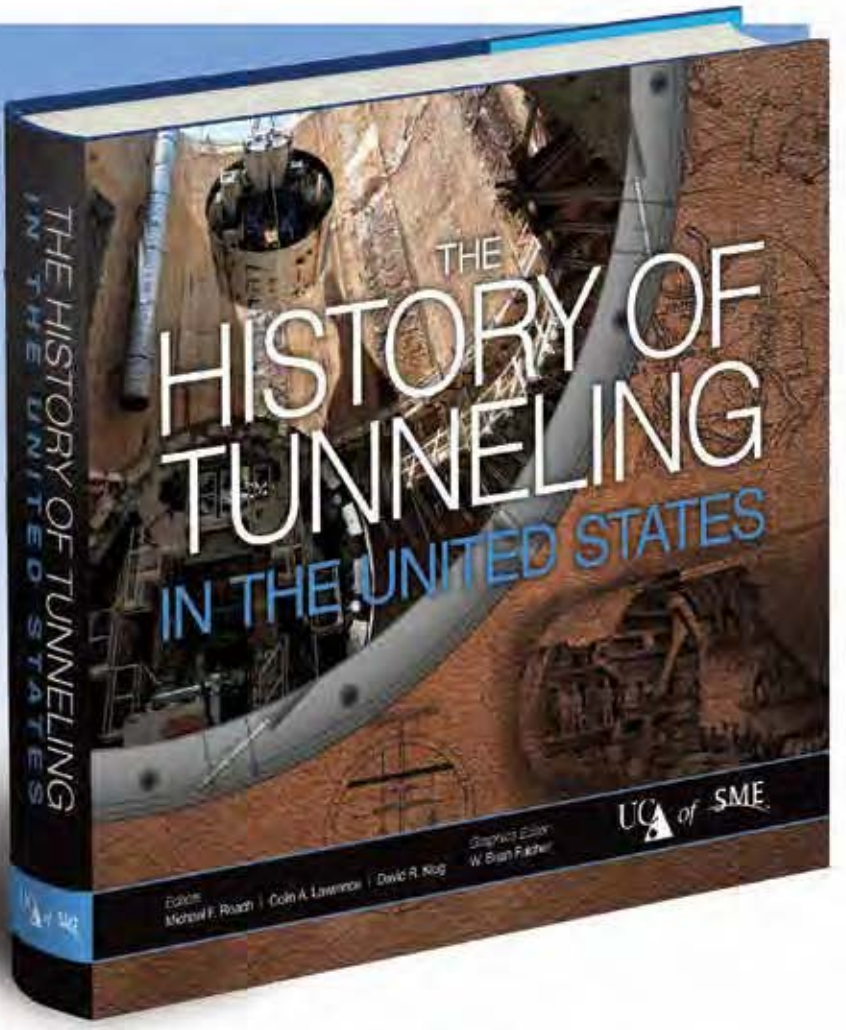
Staying true to its "Rain City" nickname, Seattle gave JCM much more ground water than expected, causing complications. The TBMs had earth pressure balance systems that pushed water away, allowing technicians to do inspections and service cutter heads, but the cross passages weren't as easy. The water volumes that needed to be pumped at some of the cross passages was far greater than what the municipal system could handle. Project leaders knew freezing the soil was a solution that would prevent structural issues and ensure safety during excavation. They originally planned to freeze five of the cross passages but expanded that to 10 after encountering the excess water. Crews again used the Brokk 400D, this time to drill holes for freeze pipe they installed within the haunches of the cross passages. They then pumped the pipes with a brine solution, chilling the soil to a frozen -12 °C (10 °F) and making it an easy target for a Brokk machine's hydraulic breaker.

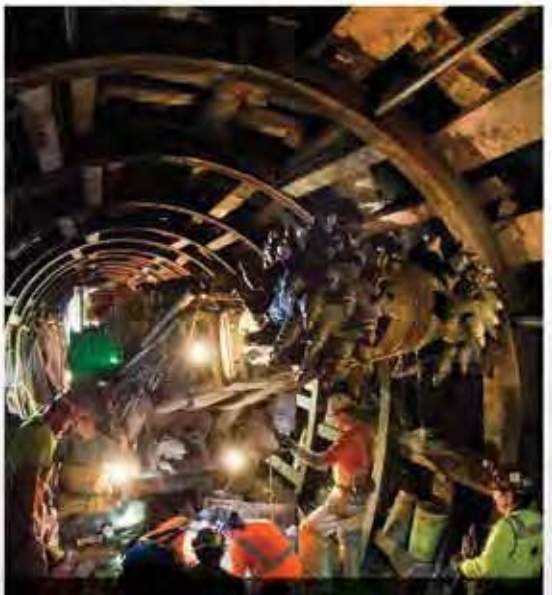
"The freezing technique is invaluable to keeping work going quickly and safely," Wood said. "It is very effective. The frozen sand ends up being like concrete until it thaws. This makes it really easy to chip away at without worrying about stability issues."

After three years of tunneling with the TBMs, JCM completed the final breakthrough on Sept. 1, 2016. In total, crews removed about 554,000 m^3 (725,000 cu yd) of material — enough to fill about 242 Olympic-sized swimming pools. JCM was to continue follow-up work until February 2018. The next contractors will continue work on the stations, rail and electrical components in preparation for project completion in 2021.

The transit plan approved by voters in 2013 also included an 13.7-km (8.5-mile) above-ground light rail extension from Northgate to Lynnwood. Project construction is expected to begin in 2018 with a goal of service starting in 2023. Voters approved another expansion including 100 km (62 miles) of new light rail and other transit additions in November 2016. The project is just one of a series of planned improvements, all part of an overall goal to relieve commuter headaches. ■

New Book Chronicles 200 Years of Tunneling in the United States





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TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Gateway Tunnel	Amtrak	Newark	NJ	Subway	14,600	24.5	2019	Design study
2nd Ave. Phase 2	NYC-MTA	New York	NY	Subway	16,000	20	2020	Under design
2nd Ave. Phase 3-4	NYC-MTA	New York	NY	Subway	105,600	20	2020-25	Under study
Water Tunnel #3 Stage 3 Kensico	NYC-DEP	New York	NY	Water	84,000	20	2020	Under study
Flushing Bay CSO Tunnel	NYC_DEP	New York	NY	CSO	13,200	20	2026	Under study
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2022	Under study
Narragansett Bay CSO Phase III - Pawtucket Tunnel Conveyance Tunnel	Narragansett Bay Commission	Providence	RI	CSO	13,000 8,800	28 10	2020 2024	Under design Under design
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	10,000	30	2018	Under design
Thimble Shoal Parallel Tunnel	Chesapeake Bay Bridge & Tunnel Dist.	Chesapeake	VA	Highway	5,700	45	2016	Dragados/ Schiavone awarded
Hampton Roads Bridge-Tunnel Project	Virginia DOT	Hampton Roads	VA	Highway	7,500	42	2018	Shortlist announced
Northeast Boundary Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	17,500	23	2017	Impregilo/Healy JV awarded
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	4,500	33	2022	Under design
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2017	Under design
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	30,000 21,000	18 14	2018 2019	Under design Under design
Westerly Main Storage Tunnel	NEORSD	Cleveland	OH	CSO	12,300	24	2020	JayDee/ Obayashi awarded
Shoreline Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,100	21	2021	Under design
Shoreline Consolidation Tunnel	NEORSD	Cleveland	OH	CSO	11,700	9.5	2022	Under design
ALCOSAN CSO Ohio River Allegheny River Mononghahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	10,000 41,700 53,900	30 30 30	2019 2020 2021	Under design Under design Under design
I-75 modernization project	Michigan DOT	Detroit	MI	CSO	22,000	14	2018	Bid date 8/21/2018
KCMO Overflow Control Program	City of Kansas City	Kansas City	MO	CSO	62,000	14	2018	Under design
Ship Canal Water Quality Project	Seattle Public Utilities	Seattle	WA	CSO	14,250	19	2018	Under design

To have your major tunnel project added to the Tunnel Demand Forecast, or to update information on a listed project, please contact Jonathan Klug at jklug@drklug.com.

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	Transit	10,500	18	2022	Under design
L.A. Metro Westside Phase 2 Phase 3	Los Angeles MTA	Los Angeles	CA	Subway	 26,500 26,500	 20 20	 2016 2017	Tutor Perini/O&G JV awarded Proposals 12/11/17
Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2018	Under study
Northeast Interceptor Sewer 2A	LA Dept. of Water and Power	Los Angeles	CA	Sewer	18,500	18	2014	Delayed indefinitely
River Supply Conduit - Unit 7	LA Dept. of Water and Power	Los Angeles	CA	Water	13,500	12	2015	Bid submitted
JWPCP Effluent Outfall Tunnel project	Sanitation Districts of LA	Los Angeles	CA	Sewer	37,000	18	2015	Bid date 4Q 2018
Two Mile Bar Tunnel	Oakdale Irrigation	Oakdale	CA	Water	5,950	11.5x13	2017	SMCI low bidder
Freeway 710 Tunnel	CALTRANS	Long Beach	CA	Highway	26,400	38	2016	Under design
BDCP Tunnel #1 BDCP Tunnel # 2	Bay Delta Conservation Plan	Sacramento	CA	Water	26,000 369,600	29 35	2018 2019	Under design Under design
SVRT BART	Santa Clara Valley Trans Authority	San Jose	CA	Subway	22,700	20	2016	Single tunnel option approved
Silicon Valley Clean Water Tunnel	Silicon Valley Clean Water	Silicon Valley	CA	CSO	17,500	13	2017	Barnard/Bassac JV awarded
Coxwell Bypass Tunnel program	City of Toronto	Toronto	ON	CSO	35,000	12	2015	JayDee/Michels/ C&M McNally Low Bidder
Highway 401 Rail Tunnel	Metrolinx	Toronto	ON	Subway	580	35x28	2017	EllisDon/Strabag JV awarded
Keswick Effluent Outfall	City of Toronto	Toronto	ON	CSO	11,600	23	2018	Under design
Yonge St. Extension	Toronto Transit Commission	Toronto	ON	Subway	15,000	18	2016	Under study
Taylor Massey Tunnel	City of Toronto	Toronto	ON	CSO	20,000	18	2018	Under design
Inner Harbour West	City of Toronto	Toronto	ON	CSO	18,400	19	2021	Under design
Scarborough Rapid Transit Extension	Toronto Transit Commission	Toronto	ON	Subway	25,000	18	2018	Under design
REM Transit Tunnel	City of Montreal	Montreal	QC	Subway	27,000	22	2017	SNC/Dragados/ Aecon JV Awarded
Newfoundland-Labrador Fixed Link	Gov. of Newfoundland/Lab	Newfoundland	NL	Transit	56,000	40	2020	Under study
Green Line LRT	City of Calgary	Calgary	AB	Transit	26,250	20	2018	Under design
Second Narrows Tunnel	City of Vancouver	Vancouver	BC	CSO	3,600	14	2013	Shortlist announced
Annacis Island Outfall	City of Vancouver	Vancouver	BC	Water	8,000	10	2017	Shortlist announced
Burnaby Mountain	Kinder Morgan	Vancouver	BC	Oil	8,000	12	2017	Under design
Broadway Sky train extension	Trans Link	Vancouver	BC	Subway	25,000	18	18	Under design
Northern Gateway Hoult Tunnel	Enbridge Northern	Kitimat	BC	Oil	23,000	20	2014	Under design

AWARDS

UCA presents four awards at NAT

Lifetime Achievement Award to Harvey W. Parker

The Lifetime Achievement Award recognizes outstanding achievements in the underground design and construction industry. The outstanding achievements recognized have been accomplished through design or construction of civil underground facilities. The winners have contributed significantly to the education, planning, design, construction or rehabilitation of tunnels and underground facilities. This includes seeking advances in new methods and materials, and advancing the public understanding and concurrence with the beneficial uses of underground space.

Harvey W. Parker received his B.S. in civil engineering from Auburn University in 1957, a masters degree from Harvard University in 1967, and his Ph.D. in civil engineering, with a minor in geology, from the University of Illinois in 1976. His specialties are tunnel and geotechnical engineering. He is a Fellow of the American Society of Civil Engineers (ASCE), a member of the Moles and is registered as a civil and a geotechnical engineer. He holds a Diplomate in geotechnical engineering from ASCE. Parker was involved in the pioneer development of steel-fiber reinforced shotcrete, improved geotechnical tunnel investigation methods and monitoring techniques, and innovative tunnel linings and tunnel support materials. He is the author or co-author of more than 60 publications. He has consulted on world-class projects, including transit systems and water, sewer, highway and hydroelectric tunnels.


PARKER

Parker has served as chair of UTRC, USNC/TT and ACI underground shotcrete committees. He has also served on the executive council of the International Tunnelling and Underground Space Association (ITA), represented ITA at the United Nations and was ITA president for three years. He also served in senior management positions and helped develop engineering staff and new markets for several firms.

Outstanding Individual Award to David R. Klug

The Outstanding Individual Award recognizes those individuals, including contractors, engineers, owners and suppliers, who have made significant contributions to the field of tunneling and underground construction and to the Underground Construction Association (UCA).

David R. Klug is the president of David R. Klug and Associates Inc. and Klug Construction Systems LLC based near Pittsburgh, PA. The companies provide international and national manufacturer representative services to the underground heavy civil and mine construction industries. They also specialize in the marketing coordination and distribution of products and specialty services for precast segmental tunnel lining, NATM, soft-ground and conventional tunnel construction practices inclusive of initial support systems, final lining reinforcement products and components for one-pass precast tunnel linings.


KLUG

Klug has more than 40 years of industry involvement in many of the major tunnel programs constructed in the United States and Canada. In conjunction with his European clients, he conducts industry outreach seminars to Europe for people from the U.S. and Canadian tunneling industry to study European methods of tunnel construction and contract delivery practices. To date, Klug has conducted 12 European tunnel seminars.

Klug received a bachelor of science degree from West Liberty State College. He is a past chair of the UCA (2009-2011), a member of the UCA Fox Conference Committee, the Moles and the Associated General Contractors of America affiliate of Western Pennsylvania.

Outstanding Educator Award to Priscilla P. Nelson

The Outstanding Educator Award is presented by the UCA Executive Committee to professors and teachers who have had an exceptional career in academia and education in the areas of underground design and construction. These individuals have also made significant contributions to the industry through their academic interests, as well as through the introduction of many student graduates into the industry. They are nominated by their peers.

Priscilla P. Nelson is professor and head of the Department of Mining Engineering at the Colorado School of Mines. She previously was provost at the New Jersey Institute of Technology, program director and senior advisor at the U.S. National Science Foundation, and professor in civil

AWARDS

engineering at the University of Texas at Austin. She has worked for the U.S. Department of Energy and the state of Texas on the superconducting super collider project, and she served two terms on the U.S. Nuclear Waste Technical Review Board.

Nelson is a Distinguished Member of the American Society of Civil Engineers (ASCE), former president of the Geo-Institute of ASCE, a lifetime member, first president and Fellow of the American Rock Mechanics Association, and a Fellow of the American Association for the Advancement of Science. She is a member of the Moles and is an Eminent Engineer with Tau Beta Pi. She received the Kenneth Andrew Roe Award from the American Association of Engineering Societies and the 2011 ASCE Henry L. Michel Award. In 2016, she was appointed chair of the Mine Safety and Health Research Advisory Committee of NIOSH.


NELSON

Nelson received a B.S. degree in geology from the University of Rochester, an M.S. in geology from Indiana University, an M.S. in structural engineering from the University of Oklahoma and a Ph.D. from Cornell. She has published more than 150 technical and scientific publications.

Project of the Year Award to Northern Boulevard Crossing, Queens, NY to Schiavone/Kiewit, AJV, WSP/Parsons Brinckerhoff and NYCMTA Capital Construction

The Project of the Year Award recognizes an individual or a group that has shown insight and understanding of underground construction in a significant project, which may include a practice, developing concepts, theories or technologies to overcome unusual problems within a project.

The construction of the Northern Boulevard Crossing, characterized by complex soil geometry, a high water table and an active, triple-level transit corridor above the tunnel alignment, is recognized as the most technically challenging aspect of New York City MTA's East Side Access project. The Crossing, approximately 12-m (40-ft) high by 18-m (60-ft) wide, 38-m (125-ft) long and 26 m (85 ft) below ground level, was constructed using the Sequential Excavation Method.

The pre-existing transit corridor consisted of an active five-track IND subway box just a few feet above the tunnel crown, the Northern Boulevard itself, and east/westbound elevated BMT tracks, all heavily traveled. Public safety during the work was critical, and protecting these structures from movement during the performance of the work was considered paramount. However, site restrictions that included groundwater drawdown limitations and a moratorium on vertical drilling from Northern Boulevard or from the overlying subway tunnel severely limited available options. A canopy of frozen ground installed above the tunnel alignment to provide the required ground water control, as well as a structural arch for the sequential tunneling operation, was considered the only technically viable option. This option was suggested by the project designer and adopted by the design-build contractor.

The project was the first sequentially excavated, soft-ground tunnel in New York City. The size of the excavated tunnel completed beneath a frozen arch is unprecedented. There were many complicating elements that had to be overcome in creating the frozen arch and constructing the tunnel, including underpinning the elevated rail line and penetrating the existing four clusters of 16 pipe piles, which were indicated without any detail on old structural drawings. There were unique and previously unattempted settlement and heave-control measures performed in conjunction with a frozen ground improvement to protect the pre-existing transit structures. Other challenges included waterproofing, which was installed in stages due to the underpinning piles, and the final lining, which was constructed using shotcrete and massive ring steel.

The complex and challenging project was marked by extensive preplanning, stringent controls, a sophisticated monitoring program and a cooperative project team effort, which resulted in problem-free tunnel excavation with no appreciable movement of the overhead structures. ■

International tunneling awards to Southland Holdings

Southland Holdings LLC received two international tunneling awards from New Civil Engineer. The company received the 2017 Tunneling Project of the Year Award (project of more than $150 million) for the Kaneohe/Kailua Sewer Tunnel Project and the 2017 Outstanding Contribution to a Project Award for the Jollyville Transmission Main Tunnel.

The Jollyville Transmission Main Tunnel, Austin, TX, was lauded for project innovations related to unique environmental conditions and endangered cave-dwelling invertebrates encountered in the project area within the Balcones Canyonlands Preserve.

AWARDS

The $87-million, 3-m (10-ft) diameter tunnel transports water more than 107 m (350 ft) below ground from Austin's Water Treatment Plant No. 4 to the Jollyville Reservoir. A public outreach program contributed to community support and positive client feedback regarding zero environmental impacts to groundwater and surface water.

The Kaneohe/Kailua Sewer Tunnel Project final tunnel liner consisted of 3-m (10-ft) Hobas glass fiber-reinforced thermosetting resin pipe grouted in place.

The Kaneohe/Kailua Sewer Tunnel Project successfully implemented the first use of a tunnel boring machine in Hawaii and on the island of Oahu. The project conveys wastewater from the Kaneohe waste water pretreatment facility to the Kailua regional waste water treatment plant to prevent overflows and spills during heavy rain events.

Working within unique island conditions, the Southland/Mole Joint Venture coordinated closely with state, city and county environmental permitting and enforcement agencies to ensure minimal impact to the project's surrounding areas. Ground water controls, community engagement, and equipment procurement and logistics were also significant factors for success. ■

STUDENT OUTREACH

Growing the next generation of tunnelers

by Paul Schmall, UCA of SME Student Outreach Chair

I had breakfast with Mesut Pervispour a couple of weeks ago. He teaches geotechnical engineering and construction at Lehigh University. Ted Dowey had just visited Pervispour to do a lecture on the Rondout Tunnel Project for his construction engineering class. Pervispour and the whole class were in awe. He recounted to me how Dowey used the site photos to bring the project to life for the students. I don't think Dowey really knew how impactful his one hour lecture was. And most of us don't know how jaw-dropping impressive underground construction work is to students who have never seen it.

Three tunneling students from Oregon Tech on a tour of the Chinatown Station Project in San Francisco, CA.

The UCA of SME Student Outreach has one overriding mission — to attract students to careers in underground construction. The hard part is getting that across to the current (and future) crop of engineering students. Tunneling is not taught in the typical undergraduate civil engineering program. Only the Moles or the Beavers reach a significant number of undergraduate civil engineering students to expose them to the world of underground construction, and that is still a limited number of students. We are trying to change that. By polling university professors, we have learned that live, on-campus presentations, such as Ted Dowey's at Lehigh, project site visits, and teaching the teachers are the things we can do to make a difference. And that is our focus now.

Two years ago, we forged a strategic alliance between the UCA and the ASCE Geo-Institute. ASCE has direct access to all of the civil engineers nationwide, and the UCA has the expertise. It is a complementary and mutually beneficial relationship. Since that time, we have coordinated several programs: university speakers, tunnel tours and a teach-the-teachers workshop.

STUDENT OUTREACH

University speakers

The number one thing that all professors want is industry people to come to their classes and show their students what the real world is like. University ASCE chapters are always looking for good speakers with interesting project case histories.

To date, we have dispatched Barry Doyle of MWH Global to the Milwaukee School of Engineering, Nick Maynard of Citizens Energy Group to Purdue, Amanda Elioff of Parsons Brinckerhoff to UCLA, Adam Curry and James Myers of Moretrench to Widener College, Allen Cadden and Joe O'Carroll of Parsons Brinckerhoff to the University of San Diego, Jeremy Kosegi of Citizens Energy Group to the University of Illinois, Gregory Raines of Stantec to the Polytechnic University at Pomona, Rozbeh Moghaddam of GRL Engineers to Texas Tech and, of course, Ted Dowey of NYC DEP to Lehigh University.

The response everywhere has been tremendous. "I cannot express how unique of an opportunity this was for our student chapter" is a typical response we hear. We have several more lectures scheduled for the fall.

Tunnel tours

The Tunnel Tours program exposes the students to life underground, so to speak. The program provides an opportunity for a small group to tour an active tunneling project, which most, if not all, of the students have never seen. With the participation of many industry professionals willing to give their time and expertise, the tours include an above-ground presentation as well as lunch with the members of the tunnel design and construction teams. This gives the students a chance to engage with experts in the field of underground construction who can give them a true picture of what will hopefully become their chosen career. While The Moles provide a similar, positive experience in the northeast with their very successful, annual Moles Students' Day, the Tunnel Tours program aims to provide the experience to students nationwide.

So far, we have hosted tours for Columbia, the University of California Davis and Oregon Tech to the Central Subway Chinatown Station Project in San Francisco; the Rose-Hulman Institute of Technology, the University of Michigan and Purdue University to the White River Tunnel in Indianapolis; North Carolina State University to the MD355 (BRAC) Crossing in Bethesda, MD; and Drexel University to Randall's Island in New York City. Special thanks goes to Liza Dwyre and Tom Pennington who have been our primary hosts and to Barnard Construction, Kiewit and Atkinson.

Teach the teachers

We are fortunate to have Mike Mooney from the Colorado School of Mines involved with the Student Outreach program. With one foot in academia and one in the industry, Mooney is uniquely capable of being a liaison between the students and the industry. He has been spearheading the first teach-the-professors workshop that will take place at NAT. The intent of this program is to collectively develop tunneling-focused content that can be woven into the undergraduate geotechnical, structures and construction courses, educate the professors in underground construction, and provide them with a suite of instructional tools. Our hope is to equip the people on the front lines every day (the professors) to promote Ted Dowey-like jaw dropping excitement in the classroom.

UCA Young Members

A lot of people have already been working hard behind the scenes or have committed to be a part of the future program. The UCA Young Members group is a great example under the leadership of Shannon Goff, Tony Bauer and Erin Clarke. Our young members section may be small, but it's active. They are working toward developing close relationships with colleges and universities with strong programs, and they host monthly online webinars for younger engineers on a range of topics. One of their goals is to provide better networking and job-seeking opportunities for young professionals. They are on board and enthusiastic about college-based presentations, and they are our first line of communication in that respect. This goal is already paying dividends. The UCA scholarships, for example, have truly taken off in the last couple of years.

What can I do to get involved?

If you have felt that somebody in your past was instrumental in shaping your career, please consider passing that forward. We all have the duty to replicate ourselves at least once. We have a solid start but welcome more member participation.

There is an impressive roster of subject matter experts to do presentations, but we lack qualified young engineers who are seasoned enough to know their subject well yet young enough to relate directly to students. Energy and enthusiasm are especially needed, but we can use anybody (older members included) that has a strong connection with any civil engineering program. There is a need for people in the heartland of the country, too. It seems that most of the expertise is on the East Coast and the West Coast, but a lot of the schools are in the middle.

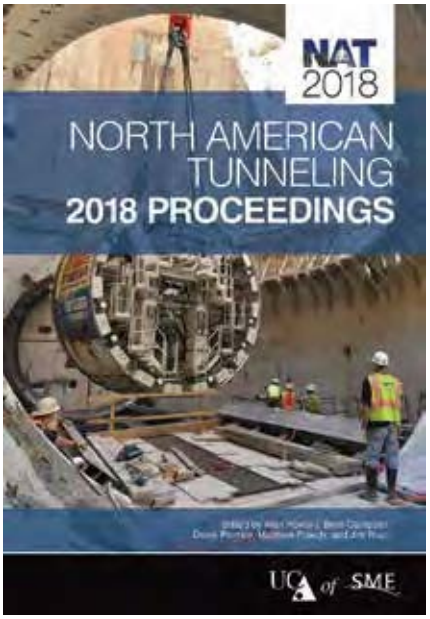
More tunneling projects need to open their doors to a handful of students at a time. If you have a project that could accommodate a couple of tours a year, please consider it. Nothing is more effective than seeing the real thing.

If you can be a part of this exciting and worthwhile initiative, or would just like more information, please contact me at pschmall@moretrench.com. ■

NEW MEDIA

North American Tunneling 2018 Proceedings

2018, edited by Alan Howard, Brett Campbell, Derek Penrice, Matthew Preedy and Jim Rush, published by SME, 12999 E. Adam Aircraft Cir., Englewood, CO 80112, USA, www.smenet.org/store, email books@smenet.org, phone 303-948-4237, 800-763-3132 x237, 1,160 pp., ISBN 978-0-87335-466-0, $149 member; $129 student member; $199 list, also available as an eBook.



The North American Tunneling Conference is the premier biennial tunneling event for North America, bringing together the brightest, most resourceful and innovative minds in the tunneling industry. It underscores the important role that the industry plays in the development of underground spaces, transportation and conveyance systems, and other forms of sustainable underground infrastructure.

With every conference, the number of attendees and breadth of topics grow. The authors — experts and leaders in the industry — share the latest case histories, expertise, lessons learned, and real-world applications from around the globe.

Crafted from a collection of 126 papers presented at the conference, this book takes you deep inside the projects. It includes challenging design issues, fresh approaches on performance, future projects, and industry trends as well as ground movement and support, structure analysis, risk and cost management, rock tunnels, caverns and shafts, TBM technology, and water and waste water conveyance. ■

SHORT COURSE

CSM offers tunneling fundamentals short course

Colorado School of Mines (CSM) will offer its internationally acclaimed Tunneling Fundamentals, Applications and Innovation Short Course Oct. 15-18, 2018.

The three-and-a-half day course weaves presentations of emerging innovations in tunneling methods, materials and technology with instruction on key principles of design and construction in all ground types and across all excavation methods.

Taught by experts from industry and CSM faculty, this course blends classroom instruction and presentations in the morning and early afternoon with hands-on laboratories and demonstrations each afternoon in the school's world-class tunneling laboratories. The labs cover a wide range of emerging advances including soil conditioning, slurries, grouts, rock cutting, abrasivity and wear, blasting, geotechnical investigation, TBM simulation, shotcrete, 3D modeling and BIM.

The course will be held on the CSM campus in Golden, CO and offers a one-of-a-kind learning experience and great networking opportunities with both industry and CSM students. For more information and to register, visit http://csmspace.com/events/tunneling.

The Colorado School of Mines Center for Underground is a collaborative, multidisciplinary group of faculty and students from civil engineering, geology and geological engineering, mining engineering and mechanical engineering, as well as geophysics and computer science, with a collective interest in education and research in underground engineering. For more information about the center, visit http://underground.mines.edu. ■

PERSONAL NEWS

DON PAINTER, a senior tunnel construction professional, has rejoined Brierley Associates and will head its new office in Honolulu, HI. Painter recently served as the project manager for Southland Mole JV during construction of the Kaneohe Kailua Sewer Tunnel. He has more than 43 years of experience, including almost 20 years working with Brierley Associates. He was senior tunnel consultant with Brierley from 2005-2008 and previously served as the general tunnel superintendent for the H3/Haiku Tunnels on Oahu. He has extensive experience with conventional and tunnel boring machine (TBM) tunnel construction for wastewater, water and transportation projects utilizing open (main beam) shielded TBMs. ■

OBITUARIES

GEORGE D. YOGGY

An Appreciation by David R. Klug

On March 27, 2018, the underground construction industry lost a leader and a gentleman with the passing of George D. Yoggy after an extended battle with cancer. Born in Morris, PA on Oct. 16, 1937, Yoggy grew up in Johnson City, NY, attended Wheaton College and was member of the U.S. Navy Reserves as a Seabee.

YOGGY

Yoggy always had a love for heavy construction and the satisfaction derived from seeing complex challenges being met, beginning with his career with a local contractor in 1956. He developed an early expertise in shotcrete design and material application systems to address specific project requirements. In 1968, he started his own company, Concrete Equipment Corp., and in 1978 he started Shotcrete Plus Inc. One of his first major projects was the shotcreting of the supportive excavation "bathtubs" for the original World Trade Center buildings in the early 1970s.

After the September 2001 terrorist attack on the World Trade Center buildings, I, and a group of other industry individuals, accompanied Yoggy on a visit of the 9/11 site to view the potential damage to the PATH Subway Tunnel lining and the condition of the 1970s shotcreted supportive excavation for the foundation bathtubs. Yoggy took great pleasure in seeing that the worked performed in the early 1970s was still preventing the Hudson River from entering the site, even after such a catastrophic event.

In 1986, his companies were acquired by Master Builders Inc. He and Anne moved to Cleveland, OH, where he created the Underground Construction Group (UCG) for Master Builders. As the leader of the UCG, he transformed the group into the domestic and international leader in the development of new concrete/shotcrete technologies and material placing systems. Yoggy was recognized internationally for the successes created by his group, but he always acknowledged that this could not have been accomplished without the high caliber people that were part of his UCG team. Many of these people now have leadership roles in the underground construction industry.

Yoggy was involved in many major underground infrastructure projects during his long career with the implementation of engineered high-performance shotcrete systems that accompanied the introduction of NATM/SEM construction practices to North America. These include the WMATA Program in Washington, DC; the Sound Transit Program in Seattle, WA; the Pennsylvania Turnpike Lehigh Tunnel and the Cumberland Gap Tunnel in Tennessee. Later in his life he was deeply involved in the expansion of the subway system in New York City by working with the major tunnel contractors in the implementation of quality shotcrete application programs for the East Side Access Program, the No. 7 Line Extension Project, and the Second Avenue Station and Tunnel Expansion Program.

Yoggy had the philosophy that one must give back to the industry and not just reap the rewards. And he did this in many ways. He was a mentor to many young people who showed an interest in the industry and a desire to learn. Having knowledgeable and dedicated people involved on industry technical committees and associations is most critical to their success, and Yoggy gave of his time freely to such endeavors.

As a member of the American Concrete Institute Committee 506, Yoggy was a leading advocate for proper shotcrete specifications. And as a founding member of the American Shotcrete Association (ASA), which was formed in 1998, he helped to make the organization the leading industry advocate for the use and proper application of shotcrete for a variety of structural concrete applications. His involvement with the development of the ASA/ACI Shotcrete Nozzleman Certification program in 1999 helped to assure that the program got off to a proper start. He was always willing to share his knowledge and experience and was a mentor to several of ASA members. His strong impact on the ASA was acknowledged, as several past presidents of the ASA, as well as the executive director, attended his memorial service in Allentown, PA.

From 1999 to 2005, Yoggy was involved in the management structure of the American Underground Association, the predecessor to the current Underground Construction Association (UCA) of SME. He was president from June 2001 through June 2003. In June 2009, he was awarded the UCA Lifetime Achievement Award for his many industry contributions. He was also active with the International Tunnel Association in conjunction with the home office of MBT that was based in Switzerland.

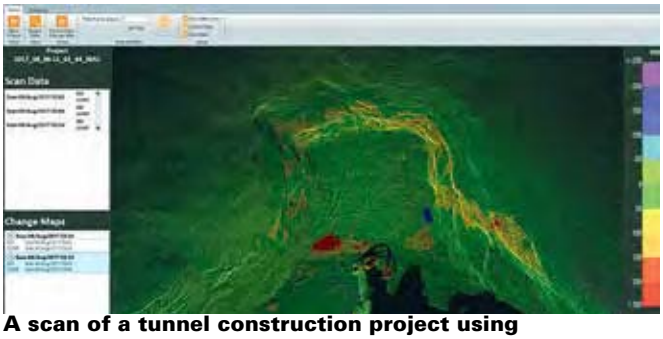
On April 21, 2018, a memorial service was held for Yoggy at his church in Allentown, PA, which

(Continued on page 38)

PRODUCTS

3D Laser Mapping releases real-time, underground monitoring

A unique scanner and software package developed by 3D Laser Mapping will boost safety, efficiency and productivity for underground operations. Processmonitor Live provides real-time, automated measurements of underground surfaces and is designed to be deployed in underground mining, construction and tunnelling. The package provides a visual representation of surface changes in processes, such as sprayed concrete applications, tunnel excavation and slope-stability monitoring. Processmonitor Live's scanner and software interface was originally designed in response to a request from a specialist shotcrete operator based in Australia and has been used extensively by its underground mining team.



A scan of a tunnel construction project using Processmonitor Live.

The system was developed in response to feedback from customers who need to place safety and productivity in equally high regard — clients who have identified that time consuming tasks can now be automated while reducing cost and risk to onsite personnel.

www.3dlasermapping.com

Sandvik offers iSURE software for tunneling construction

Intelligent Sandvik underground rock excavation software (iSURE) is a computer program for tunneling construction and mining drill and blast process control. It produces all the data needed for an optimized drilling and blasting cycle. The full-featured iSURE software utilizes the drill rig's data collection to improve the work cycle and the drill and blast excavation process. It also has an optional toolset for geological analysis, iSURE GEO, a tunnel profile 3D scanning system, iSURE 3D SCAN, and an interface to a third-party blasting vibration feedback system. iSURE software capitalizes the improved accuracy of iSeries rigs for drill and blast usage.

Together, the iSURE software and DT922i tunneling jumbo, the newest addition to Sandvik's extensive tunneling offering, create a combination designed to change the future of tunneling. The fully automated DT922i tunneling jumbo brings quality, reliability and exceptional versatility. With a new articulated carrier, it features a next generation cabin supplying 25 percent increased visibility and a noise level of less than 69 dB at all times. Sandvik DT922i is a computer-controlled, two-boom, electro-hydraulic drilling jumbo with an articulated carrier for tunneling excavation of 12-125 m^2 (129-1,345 sq ft) cross sections, including face drilling, bolt hole drilling and mechanized long-hole drilling. ■

www.rocktechnology.sandvik

OBITUARIES

YOGGY

(Continued from page 37)

I attended. Approximately 25-30 people from the underground construction industry were there to pay their respects to a man held in high esteem by the industry and all of the 250 people in attendance.

I knew George Yoggy for more than 30 years. He was always a gentleman and willing to lend a hand. He will be missed by the many people who came to know him and benefited from his wisdom and guidance. Rest in peace George, it is well deserved.

George Yoggy is survived by Anne, his wife of 59 years; three children, Kimberly, Lynn and Kirk, and eight grandchildren. The Yoggy family has established a scholarship fund with the Moles organization to help the next generation of industry engineers.

Individual or company contributions can be made to the George Yoggy Moles Scholarship Fund, 50 Chestnut Ridge Rd., Ste. 102, Montvale, NJ 07645. ■

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Tunneling: A Capital Idea

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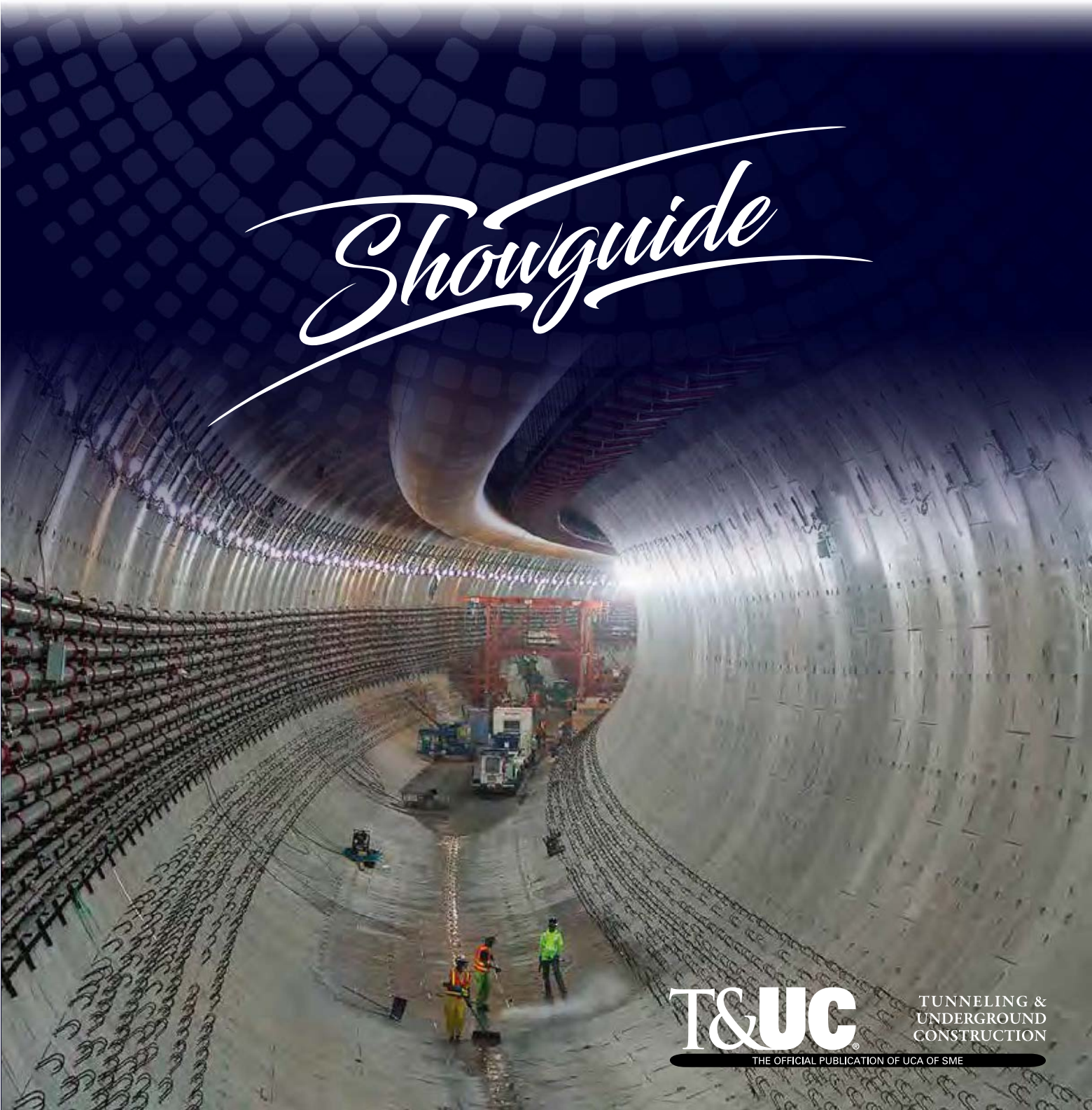

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NAT 2018

2018 NORTH AMERICAN TUNNELING CONFERENCE

Tunneling: A Capital Idea

June 24 - 27, 2018
Washington, D.C.

Showguide

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National Tunnel Practice
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Mobile 1-646-652-9440
szlatanic@hntb.com

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Tunnelling Systems

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Herrenknecht is a technology and market leader in the area of mechanized tunnelling systems. As the only company worldwide, Herrenknecht delivers cutting-edge tunnel boring machines for all ground conditions and in all diameters – ranging from 0.10 to 19 meters. The Herrenknecht product range includes tailor-made machines for transport tunnels (Traffic Tunnelling) and supply and disposal tunnels (Utility Tunnelling). Furthermore, Herrenknecht supplies an entire range of innovative machines for the mechanized construction of underground mining infrastructures. The company also produces state-of-the-art deep drilling rigs that drill down to depths of 8,000m and plants for the exploration of shallow geothermal energy.

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utt
MAPEI

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Mapei's Underground Tunneling Technology (UTT) category offers a complete line of products and associated technologies for use in and on underground construction projects, including shotcrete accelerators and admixtures for concrete, as well as products for injection and consolidation, mechanized tunneling (TBM), engineering and soil stabilization, coating and protection, maintenance, repair and waterproofing.

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TERRATEC

TERRATEC is a world-renowned Australian-based designer and manufacturer of tunnel boring machines, raise boring machines and other custom-made equipment for tunneling and mining applications. TERRATEC's success is based on the experience and excellence of its engineering team, which includes engineers with more than 40 years' experience in the design and manufacture of tunneling and mining machines for some of the world's largest underground projects. TERRATEC is fully managed by engineers and this gives quick and efficient solutions to meet customer expectations. TERRATEC products are well-known in the industry as robust, durable and safe, basic principles that must prevail in the design of any equipment made to work in the extreme conditions encountered underground. For more information visit www.terratec.co.

WSP

WSP USA

For more than a century, WSP has advanced tunneling technology with landmark projects that have shaped the course of tunnel engineering and defined industry practice. Our achievements in underground engineering include road, rail and water conveyance tunnels in hard rock, soft ground, mixed-face conditions and under water. From program management to design to construction management, we serve clients in the rail, highway, water, utilities, mining, scientific research, power and energy industries. Our designs have resulted in record-setting advances with tunnel boring machines and we have employed innovations such as earth-pressure-balanced and slurry-face tunneling techniques and fiber-reinforced concrete liners. www.wsp.com

SHOWGUIDE exhibitor listings as of April 17, 2018

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Forty three years ago, Timothy Barnard founded Barnard Construction Company, Inc. Since then, our privately held company has grown into a multimillion-dollar contractor, with a bonding capacity exceeding $2 billion. Over these four decades, we have built our reputation on skill, innovation, reliability, safety, and our ability to complete projects on budget and ahead of schedule. Among our Barnard companies and affiliates, we have extensive experience in all aspects of construction, including tunnels and shafts, dams, reservoirs, hydroelectric power, utilities, pipelines, power transmission, oil and gas, and environmental efforts. Headquartered in Bozeman, Montana, we construct projects throughout North America.

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Through its Master Builders Solutions brand, BASF is a leading supplier of underground construction solutions that help tunneling customers to become more successful, even in highly challenging ground conditions. BASF has the largest range of products and services available to meet needs and solve problems in TBM and conventional tunneling, whether in soft ground or hard rock conditions. We offer a full range of MasterRoc® tunneling products such as soil conditioning foams and polymers, anti-clay agents, tail sealants, anti-abrasion agents, dust suppressants, bearing seal greases, EP2 greases and annulus grouts, plus product for sprayed concrete and injection for ground consolidation.

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FKC-Lake Shore serves the underground heavy civil and mining industries throughout North and South America. We offer design-build-install services for innovative hoisting, elevator, and vertical conveyance systems used to transport personnel and material. Our Field Services Division provides routine maintenance, inspections, wire rope NDT, and 24/7 emergency repair of electrical and mechanical systems. FKC-Lake Shore products and services include: Vertical Belts, Skips, Hoists, Sheaves, Elevators, Cages, Headframes, Brakeman Cars, Controls, Field Services, and Wire Rope NDT.

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Jacobs

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For more than 50 years, Kiewit has built some of the most complex tunneling and underground projects in North America. We have the capabilities to self-perform soft ground and hard rock TBM tunneling, along with conventional tunneling techniques such as Drill and Blast, and SEM. At the heart of these projects is a workforce dedicated to industry-leading safety performance and unmatched quality excellence. From the unique, complex projects we build, to the committed professionals who design, engineer and construct them, Kiewit ensures the ordinary is always extraordinary.

Kiewit Infrastructure Co.
Underground District
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(402) 342-2052

Skanska

Skanska USA is one of the largest, most financially sound construction and development companies in the U.S., serving a broad range of clients including those in transportation, power, industrial, water/wastewater, healthcare, education, sports, data centers, government, aviation, life sciences and commercial. Throughout the 31 metropolitan areas where it works, Skanska has extensive tunneling and complex underground experience and expertise in support of a variety of infrastructure sectors.

Jay Weisberger, APR, LEED AP
Vice President
Head of Communications, West
Skanska USA Inc.

Stantec

Communities are fundamental. Whether around the corner or across the globe, they provide a foundation, a sense of place and belonging. That's why at Stantec, we always design with community in mind. We care about the communities we serve—because they're our communities too. We're designers, engineers, scientists, and project managers, innovating together at the intersection of community, creativity, and client relationships. Balancing these priorities results in projects that advance the quality of life in communities across the globe. Stantec trades on the TSX and NYSE under the symbol STN. Visit us at stantec.com or find us on social media.

Don Del Nero, Vice President
Email: don.delnero@stantec.com
(678) 327-2929

Bronze Level Sponsors

Babendererde Engineers

BabEng specializes in mechanized tunneling and underground storage construction. The world-wide services range from project development and design to construction management and practical work process optimization. Another successful service being offered is hands-on troubleshooting on-site for TBMs in difficult situations. For water and gas storage, BabEng joins forces with project developers and construction companies. TPC Tunnelsoft, the software branch, supports the tunneling industry with specialized software for technical data management and visualization on tunnel projects. Its unique flexibility, combined with powerful automatic reporting and notification tools, makes it one of the leading solutions in the market.

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38777 Schoolcraft Road
Livonia, MI 48150
Telephone: (734) 591-3430
Email: estimating@jaydee.us

Lovsuns Tunneling Canada Ltd.

Lovsuns is a LNSS company that acquired the entire assets of Caterpillar Tunneling Canada Corp. (formerly known as LOVAT) in 2014. Lovsuns continues to build on the 40+ years of TBM manufacturing legacy and is specialized in engineering and manufacturing full range of tunnel boring machines for both traffic and utility tunnel projects around the world, including EPB, single shield, double shield and dual mode convertible TBMs. By leveraging our modern and high-capacity factory in China, Lovsuns is fully committed and capable of supplying new TBM and legacy LOVAT TBM refurbishment support solutions for our global customers.

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Traylor Bros., Inc. (TBI) is a family-owned corporation founded in 1946. For more than 72 years, TBI has provided single-source, comprehensive, cutting-edge construction and design-build services to public works agencies throughout North America. Headquartered in Evansville, Indiana, TBI has regional offices in Long Beach, California; Lakewood, Colorado; and Alexandria, Virginia. TBI capitalizes on state-of-the-art technology for its soft ground, hard rock, and drill and shoot tunnel projects worldwide. We have successfully completed more than 110 tunneling projects, including two of the most technically demanding EPB tunnels in the United States and over 100 miles of tunnels utilizing tunnel boring machines. Our services also include drill and blast tunnels and precast tunnel segments.

Michael Roach
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NORTH AMERICAN TUNNELING CONFERENCE

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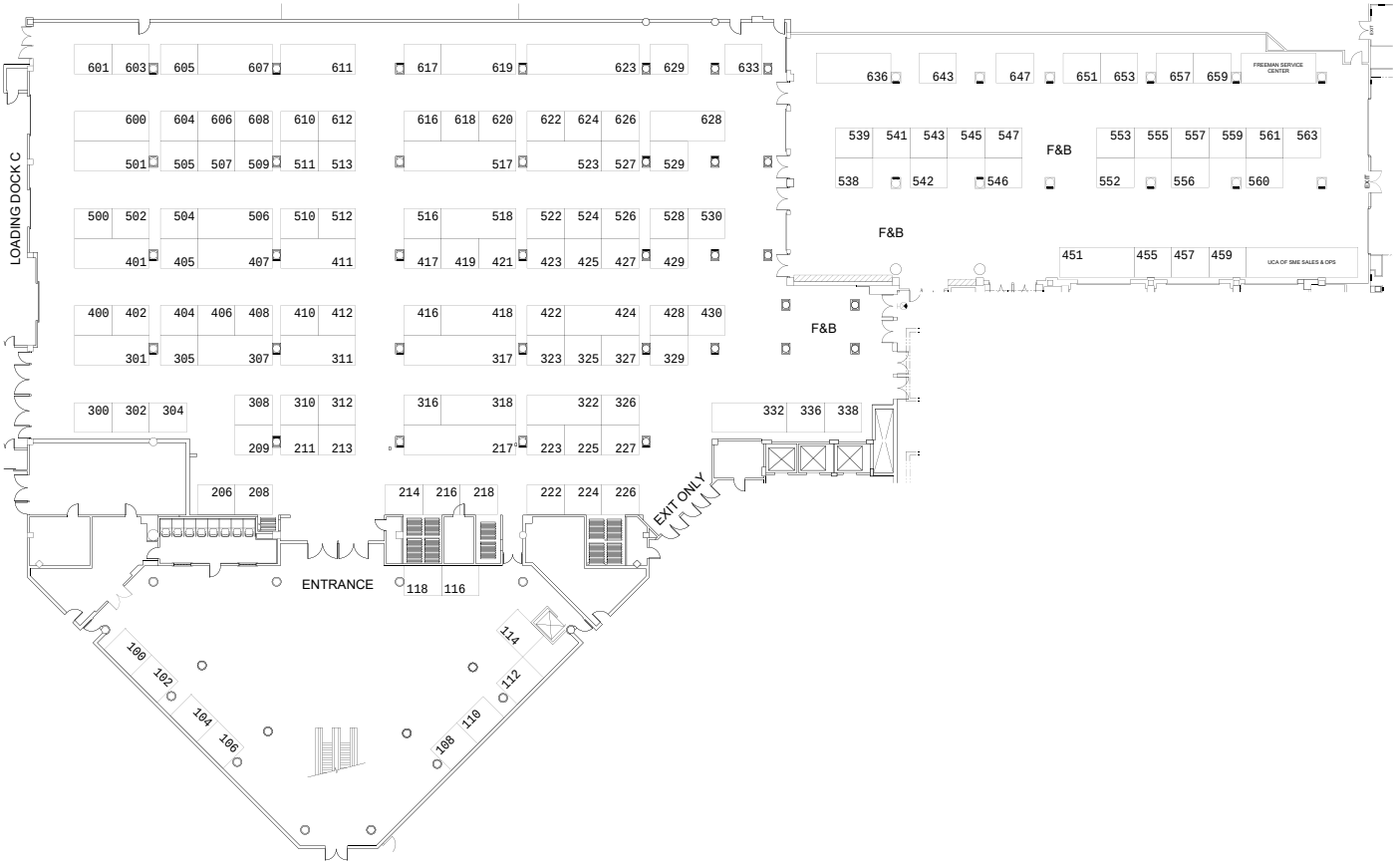

Exhibit Hall **Hours**

Monday, June 25	5 PM – 7 PM
Tuesday, June 26	11 AM – 2 PM, 4 PM – 6 PM
Wednesday, June 27	9 AM – 12 PM

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Booth: 305

See our ad on page 8

For over 90 years, ABC Industries continues to be a leading supplier of high quality, customized ducting solutions in mine, tunnel and underground construction operations worldwide. As these operations continue to evolve, ABC proactively collaborates with industry professionals to engineer unique, premium ventilation products. A new innovative addition to ABC's arsenal, RigiVent™ is a flexible, interlocking ducting solution for positive pressure applications requiring minimal storage and ease of handling. Similar to RigiDuct®, RigiVent™ is constructed from filament wound fiberglass rovings and reinforced with polyester fibers for added strength and resiliency. Visit our website to see more innovative solutions.

Products & Services

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Main Office

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ABC Ventilation Systems

Booth: 322

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Booth: 225

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Concrete Mixing and Transportation Equipment

Main Office

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AECOM

Booth: 500

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Fax: (216) 622-2301
Email: david.mast@aecom.com

Aerix Industries

Booth: 542

Aerix Industries (formerly Cellular Concrete Solutions), manufactures and supplies a dynamic product line of integrated engineered foam liquid concentrates, enabling its customers to produce and install high quality lightweight cellular concretes, ideal for annular grouting, tunnel arch backfill and flowable fill. The company's foams also allow its customers to transport tailings, sand, or other construction materials using minimal amounts of water. Aerix Industries dedication to research and technical support has allowed it to provide advanced engineered foam solutions to the construction and mining industries for more than 70 years.

Products & Services

Ground Improvement Equipment and Services
Grouting Services, Equipment and Materials

Main Office

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Golden, CO 80403 USA
Telephone: (303) 271-1773
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www.aerixindustries.com

Agru America, Inc

Booth: 300

Since 1988, Georgetown, SC–based Agru America, Inc. has been the world's leading manufacturer of flat die extrusion geomembranes, geonets, geocomposites, geotextiles, geo clay liners, concrete protective liners and fittings. Agru America also supplies vertical barrier systems and piping systems for the U.S. and international markets. The company's state-of-the-art products include Sure-Grip® CPL, Hydroclick®, Agru Smooth Liner® / MicroSpike® (structured textured products), Super Gripnet®, and Drain Liner®. Agru America is part of the worldwide AGRU Group, an Austrian family-owned business since 1948 with production facilities in Austria, the U.S., Germany and China, and distribution in over 80 countries worldwide.

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Main Office

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www.agruamerica.com

AIL Mining

Booth: 510

AIL Mining designs and manufactures a 4 flange and 2 flange shaft or tunnel liner plate which is 10 times stiffer and 5 times stronger than traditional steel liner plate • Diameters in excess of 25 m/82 ft„ • Custom sizes and shapes available„ • Fabricated elbows • Easy to ship and install • Accelerated assembly, easier fitting of plates • Smaller crews needed, lower installed costs • Added safety, structures can be built from one side • Facilitates curved structures • Allows for leak-resistant structures • Structures can be dismantled and removed.

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Fabrication Materials
Steel Pipe
Tunnel Lining and Support Materials
Ventilation Systems, Materials and Equipment

Main Office

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Stoney Creek, ON L8E 6E7 Canada
Telephone: (289) 775-8958
www.ailmining.com

Akkerman

Booth: 633

Established in 1973, Akkerman develops, manufactures and supports quality pipe jacking and tunneling equipment that accurately installs a variety of underground infrastructure. We partner with contractors to explore project solutions for a wide range of geology, pipe diameters and lengths. We are committed to making every effort to position our equipment on your next pipe jacking or tunneling project. Akkerman systems are available for purchase, lease-to-purchase, or rent from our rental fleet.

Products & Services

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Main Office

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www.akkerman.com

Alchemy-Spetec

Booth: 659

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Products & Services

Grouting Services, Equipment and Materials

Main Office

4508 Bibb Blvd, Ste B5
Tucker, GA 30084 USA
Telephone: (404) 618-0438
www.alchemy-spetec.com

Algaher S.A.

Booth: 559

We are a Spanish company that designs and produces EPDM gaskets and profiles since 1987. We work different materials depending on the Standards of application. We are specialized in designing and producing Tunnel Segment Gaskets. We are capable of manufacturing glued, anchored and hydrophilic gaskets. All our productions are made according to STUVA Recommendations and EN 681-1 standard. We have designed, manufactured and supplied tunnel segment gaskets to over than 50 projects around the world in the last years: EEUU Miami Dade Water Project, Saudi Arabia Metro Riyadh, Australia Transcity Brisbane and many others. A project a challenge.

Products & Services

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Main Office

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www.tunnelsegmentgaskets.com

Alpine Equipment

Booth: 211

Alpine pioneered the use of hydraulic cutterhead attachments (Rockwheels) in North America and continues to lead in the technological development of these rock cutting machines. Now operating under the banner of Rockwheel Americas we've expanded our product line of the most advanced hydraulic cutterheads in the world. Our sales and engineering team is glad to assist with equipment selection and if a custom solution is called for, we've got a long history of experience to draw from. Factory service and support in the USA means a rapid response and our deep inventory and rental fleet means we've got you covered.

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Scaling
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Underground Excavation Services and Equipment

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Fax: (814) 355-0046
www.alpinecutters.com

Amberg Technologies Ltd

Booth: 653

More than 35 years the Swiss company Amberg Technologies has been one of the global leaders specialised in user-friendly surveying solutions. The Amberg Tunnel product portfolio offers the customer an innovative and reliable solution and supports tunnelling in all construction phases. The system solutions under the umbrella name of Amberg Tunnel combine precise measuring instruments with task-specific software and are nowadays an indispensable tunnelling equipment component. Significant improvements in efficiency are realised, especially in tunnel navigation, tunnel profile measurements, tunnel scanning, geotechnical analysis and as-built tunnel analysis.

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American Chemical Technologies, Inc
Booth: 604

American Chemical Technologies, Inc. (ACT) manufactures and distributes biodegradable, fire-resistant, and water-soluble lubricants for TBMs across the globe. EcoSafe® FR hydraulic fluid & EcoGear gear oil technology represents a significant advancement in synthetic, fire-resistance, and biodegradability. Neptune® Series lubricants meet the same requirements for demanding industrial applications. Additionally, Neptune® Series offer a non-sheening, 100% water-solubility, and an excellent aquatic toxicity profile; score in the practically non-toxic category according to the U.S. Fish and Wildlife Classification. ACT commits to setting new standards for product performance and "Pride in Personal Service."

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Amix Systems Ltd
Booth: 227

Amix Systems Ltd., is a design, engineering and fabrication team that solves problems for today's most challenging grout mixing & backfill projects. We take complex project needs and build automated, self-cleaning products and systems that simplify the grout mixing process. The Perfect Storm series of plants produce outputs from 2m3/hr over and above 100m3/hr. Also, if you are retrofitting existing plants, we are your solution. Our team has a deep expertise in systems design and control automation. It's not about selling systems, we're on a mission to help companies reduce their overall equipment costs and make significant advances in productivity.

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Telephone: (604) 746 0555
www.amixsystems.com

Antraquip Corp
Booth: 311

See our ad on page 11

Antraquip continues to build on its reputation as the leading supplier of rock and concrete cutting attachments for excavators which are commonly used for scaling, profiling, mixing/remediation and tunnel enlargement projects, as well as roadheaders for tunnel and mining applications. In the field of tunnel support, Antraquip offers lattice girders, steel ribs and complete casing systems for pipe roofing, anchoring and drainage. Other products offered include self-drilling rock bolts, steel fibers, rock saw attachments and custom engineered shaft sinking equipment.

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www.antraquip.net

ASI Marine
Booth: 522

Established in 1987, ASI Group Ltd. is a full-service engineering and marine technology company comprised of two groups; ASI Marine and ASI Water. ASI Marine provides industries worldwide with leading edge underwater services focused on assessment, maintenance, rehabilitation and construction of underwater infrastructure and tunnels. ASI Marine, partnered with Associate Underwater Services (AUS) provide turnkey hyperbaric intervention tunneling support services to the tunneling industry. To date, ASI has performed over 500 hyperbaric interventions in soft ground tunnels.

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Branch Offices
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Stoney Creek, ON L8E 5P1 Canada
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Email: info@asi-group.com

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Avanti International
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www.avantigrout.com

Babenderede Engineers, LLC
Booth: 216

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BabEng specializes in mechanized tunneling and underground storage construction. The world-wide services range from project development and design to construction management and practical work process optimization. Another successful service being offered is hands-on troubleshooting on-site for TBMs in difficult situations. For water and gas storage, BabEng joins forces with project developers and construction companies. TPC Tunnelsoft, the software branch, supports the tunneling industry with specialized software for technical data management and visualization on tunnel projects. Its unique flexibility, combined with powerful automatic reporting and notification tools, makes it one of the leading solutions in the market.

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www.ballardmc.com/projects/tunnel-support/

BASF Corporation
Booth: 401

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Through its Master Builders Solutions brand, BASF is a leading supplier of underground construction solutions that help tunneling customers to become more successful, even in highly challenging ground conditions. BASF has the largest range of products and services available to meet needs and solve problems in TBM and conventional tunneling, whether in soft ground or hard rock conditions. We offer a full range of MasterRoc® tunneling products such as soil conditioning foams and polymers, anti-clay agents, tail sealants, anti-abrasion agents, dust suppressants, bearing seal greases, EP2 greases and annulus grouts, plus product for sprayed concrete and injection for ground consolidation.

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BAUER-Pileco Inc
Booth: 546

BAUER-MAT is a mid-size mechanical and plant engineering company with more than 20 years experience in the Tunneling/Microtunneling Industry. MAT designs and manufactures equipment for mixing, handling and separation applications for bentonite and cement slurries; mixers and mixing plants for colloidal mixing of slurries; screening, cyclone and decanting plants for solids-liquids separation. Recently BAUER-MAT introduced the BE-550 for use on bentonite slurries. The BE-550 comprises two adjoining identical standalone plants and is capable of processing 550m3 of slurry per hour and when combined with MAT's BD-90 big bowl centrifuge provides a closed circuit system with minimum footprint requirement.

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Bekaert Maccaferri Underground Solutions
Booth: 318

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Brokk Inc

Booth: 407

See our ad on page 15

BROKK is the world leader in electrically powered remote controlled demolition machines, which are used extensively in tunneling, cross-passages, shaft sinking, micro-tunneling, scaling, and other underground construction applications. BROKK machines can be equipped with a variety of attachments, such as hydraulic breakers, rock drills, rotary drum cutters, digging buckets, beam manipulators, and shotcrete nozzles. Boasting an impressive power-to-weight ratio, these compact machines can operate effectively in limited access, confined spaces, with zero-emissions. Operators can remain at a safe distance while they maneuver BROKK machines in challenging areas underground.

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www.brokkinc.com

Brookville Equipment Corp

Booth: 430

See our ad on page 16

Brookville is a leading manufacturer of rail-mounted diesel and battery-powered tunneling locomotives and personnel carriers. Featuring planetary final drive gear reducers at each wheel end to divide driveline torque, shock loading for reduced stress and longer service life, and liquid-cooled internal wet disc brakes to extend brake life and provide maximum braking capacity for long, continuous grades, Brookville units are designed for dependability. Optional equipment features include explosion proofing and patented on-board rerailing systems to enhance safety in all work environments. Brookville also manufactures rubber-tired equipment, ideal for steep tunnel grades, inspections, and maintenance for non-tracked projects.

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Cascade Drilling L.P.

Booth: 425

Cascade Drilling LP is a full service provider of drilling services specializing in the application of its Sonic drilling system for tunnel professionals globally. Cascade has applied the Sonic system for numerous soft ground tunnel projects globally in support of both design and construction efforts.

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Drilling Services and Equipment

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www.cascade-env.com

Case Foundation - Bencor

Booth: 323

See our ad on page 17

Case Foundation Company and Bencor are both part of the connected companies of Keller, the world's leader in geotechnical solutions. Case is an industry leader in providing full-service deep foundation techniques in the U.S. Case specializes in earth retention systems used for tunnel shaft construction such as secant pile walls. Bencor provides slurry diaphragm walls for support of excavation during the construction of tunnels or shafts along with a range of ground improvement /stabilization methods. With over 50 years of experience and a well-maintained equipment fleet, Bencor & Case have proven track records of completing projects on-time and on budget.

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www.kellerfoundations.com

CDM Smith

Booth: 429

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CDM Smith provides lasting and integrated solutions in water, environment, transportation, energy and facilities to public/private clients worldwide. As a full-service engineering and construction firm, we deliver exceptional client service, quality results and enduring value across the entire project life-cycle. CDM Smith's underground construction staff includes geotechnical, structural, and civil engineers and geologists located across the globe. With a full range of tunnel related services, we provide planning, feasibility and design - both 2D and 3D FEM analyses, construction services, program management, inspection and geotechnical instrumentation monitoring and data interpretation.

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ChemGrout, Inc

Booth: 224

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ConShield Technologies

Booth: 118

CONmicSHIELD® is an EPA-registered, liquid admixture that prevents MIC corrosion in combined and sanitary concrete tunnels other structures. Dosed directly into the concrete or mortar during the shotcrete, gunite, poured-in-place, and precast processes, CONmicSHIELD® is not a surface treatment or coating that can wear off, wash off, delaminate, or peel. It is an integral component of the concrete added during mixing, providing protection throughout the entire thickness at less cost. Crystal-X® products are CONmicSHIELD® compatible concrete additives for economical and effective waterproofing protection of new and existing concrete tunnels, subway systems, and other concrete structures where water damage may occur.

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COWI North America
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Crux Subsurface, Inc
Booth: 406

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Crux is a leader in geotechnical construction and exploration. With more than 15 years' experience in the tunneling industry, the company has provided solutions to some of the most difficult-access and geologically challenging projects in North America. Crux specializes in long range deviation-controlled horizontal core holes, borehole surveying, optical and acoustical televiewer services, high-quality sampling, and instrumentation installation. Pre-excavation stabilization services include dewatering, permeation and compaction grouting, tube arch canopies, and cased horizontal boreholes. Crux provides design-build services and a fleet of custom designed equipment to ensure unique project needs can be met.

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CTS Cordes tubes & seals GmbH & Co KG
Booth: 422

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Daigh Company, Inc

Booth: 504

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Booth: 214

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www.datwyler.com

David R. Klug & Associates, Inc

Booth: 418

See our ad on page 21

David R. Klug & Associates, Inc. provides manufacturers representative services to the underground civil and mine construction industries. The company specializes in products and services for soft ground, conventional, and NATM/SEM tunnels. Expertise is offered in the supply of componentry used in precast tunnel linings inclusive of EPDM gaskets, plastic and steel connectors, grout lifting assemblies and steel segment moulds plus final lining forming systems for C-I-P applications. Through their distribution company, Klug Construction Systems, LLC offers GFRP rock bolts and soft-eyes, steel and synthetic fiber reinforcement, prefabricated mesh and rebar reinforcement plus specialty grout systems for tunnel backfill requirements.

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Derrick Equipment Co

Booth: 608

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Derrick is a family-owned and operated company with a global presence focused on pioneering fine-separation technology. Since 1951, Derrick has manufactured fine separation and dewatering equipment for the Mining and Aggregates industries. In 1988, Derrick branched out into the Civil Construction industry. From ruggedly dependable dewatering to slurry separation, Derrick's innovative technologies are applicable to a global customer base and many worldwide markets. Derrick has remained dedicated to complete in-house manufacturing of every machine, screen panel, and tank system. Each unit is created and assembled at Derrick's Buffalo, New York headquarters facility. To discover more, visit Derrick's website.

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www.derrick.com

Dr. Sauer & Partners Corp
Booth: 410

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Dr. Sauer & Partners has been in practice in the United States for over 30 years, and employs tunnel engineers at Main Offices located in Washington D.C., London and Salzburg. The firm provides cost effective and innovative tunneling solutions using conventional mining approaches to owners and contractors. Dr. Sauer & Partners is recognized worldwide as one of the leading consultants for design and construction supervision of tunnels and underground structures. The application of innovative design solutions and high quality field supervision has led to the successful completion of numerous transportation and utility tunnels.

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Drill Tech Drilling & Shoring Inc
Booth: 110

Drill Tech is a drilling, tunneling, and shaft sinking contractor. Recent drilling and shoring work includes foundations for high rise buildings in San Francisco, and station excavations for San Francisco's Central Subway and L.A. Metro's Crenshaw/LAX Line. Notable recent tunneling projects include a 2000' tunnel mined through sandstone uphill at 13% grade using a Drill Tech shop built cog railroad. Drill and blast work includes a 1,000 foot deep shaft in Wyoming, and roadheader work includes 14,200 feet of mine access decline tunneling for Barrick Gold in Nevada. We also do pipe jacking and box jacking under freeways and railroads.

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Fax: (925) 978-2063
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SHOWGUIDE exhibitor listings as of April 17, 2018

DSI Tunneling LLC

Booth: 517

See our ad on page 25

DSI Tunneling LLC Inc. is a world leader in ground support systems for the tunneling industry. DSI manufactures a variety of Roof Bolts, Steel Ribs, Liner Plates, Lattice Girders & Canopy Umbrella Systems for its customers ground support needs. DSI's Equipment Division represents some of the world's best known products in tunneling, from Communications Equipment to Rock Drills. DSI is proud to represent such companies as Biomarine Tunnel Rescue Equipment, Boart Longyear Drilling Products, Condat lubriciants, Montabert Hydraulic Drifters, Hany Grouting Equipment, Strata Worldwide Communication Equipment..

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Rock Drills
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Tunnel Lining and Support Materials

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Fax: (502) 473-0707
www.dsiunderground.com

EC Applications - Tunnel Lining

Booth: 302

EC Applications supplies and installs protective tunnel liner systems combining the advantages of thermoplastics (HDPE and LLDPE) with associated materials (geotextile, waterbar, injectable grout hose and components) required for a turnkey tunnel lining system. ECA's qualified installation technicians, project experience and Los Angeles based fabrication facility provide a cost effective solution for geomembrane tunnel lining on any project.

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www.tunnellining.com

Elasto Plastic Concrete

Booth: 612

See our ad on page 27

Products & Services

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Tunnel Lining and Support Materials

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Englo, Inc, DBA Engart, Inc

Booth: 618

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Epiroc

Booth: 501

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Epiroc is responsible for the sales, aftersales service and rental of equipment for surface and underground rock excavation, civil works and infrastructure projects, exploration drilling, rock reinforcement, and ground engineering. The company is headquartered in the US near Denver, Colorado. Employing approximately 450 people, it extends its reach through a nationwide network of sales and service stores and specialist drilling distributors.

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Geocomp Corp/GeoTesting Express, Inc

Booth: 312

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Booth: 552

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Grindex Pumps

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Booth: 526

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Booth: 620

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Hayward Baker Inc

Booth: 325

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HNTB Corp

Booth: 223

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Booth: 555

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Booth: 607

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King Shotcrete Solutions
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Tunnel Boring Equipment

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Mapei Corp
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Matrix Design Group
Booth: 301

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McMillen Jacobs Associates

Booth: 316

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McMillen Jacobs Associates is a mid-sized multi-disciplined firm, with self-performing design-build capability. We are experts in tunneling and water resources and deploy that expertise to serve water, wastewater, transportation, hydropower, energy, aquaculture, and regulatory clients using a wide range of delivery methods. For over 60 years, we have worked closely with our clients at every stage of a project, assisting them with planning, design, project management, construction, and start-up services. McMillen Jacobs Associates maintains offices covering North America and Australasia.

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Measurand Inc

Booth: 538

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Michels Corp

Booth: 527

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Booth: 603

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Mining Equipment Ltd
Booth: 506

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Moretrench
Booth: 326

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Moretrench, a division of Hayward Baker, is a leader in providing the ground support and groundwater control necessary for deep shafts, tunnels and adits, underground structures, and launch and retrieval boxes. Services include: ground freezing; jet, compensation, and compaction grouting; dewatering; and groundwater treatment. Our expertise has been put to work on the most complex and challenging projects. Proud to now be part of Hayward Baker, bringing you enhanced resources, capabilities, and local expertise across North America and abroad.

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Mott MacDonald
Booth: 451

Mott MacDonald provides tunnel design and engineering solutions for rail and transit, road, water/wastewater conveyance, CSO storage, and cable and communications. With a reputation for technical excellence, Mott MacDonald identifies practical approaches to tunneling, equipment selection and contracting approaches. Expertise includes soft ground and rock tunneling, cut and cover, underground caverns, immersed tube tunnels, jacked tunnels, and microtunneling. Complementary skills in technical areas include tunnel rehabilitation, ground stabilization and treatment, tunnel systems, ventilation, and life safety and security. With 16,000 employees worldwide, Mott MacDonald is one of the world's largest employee-owned companies.

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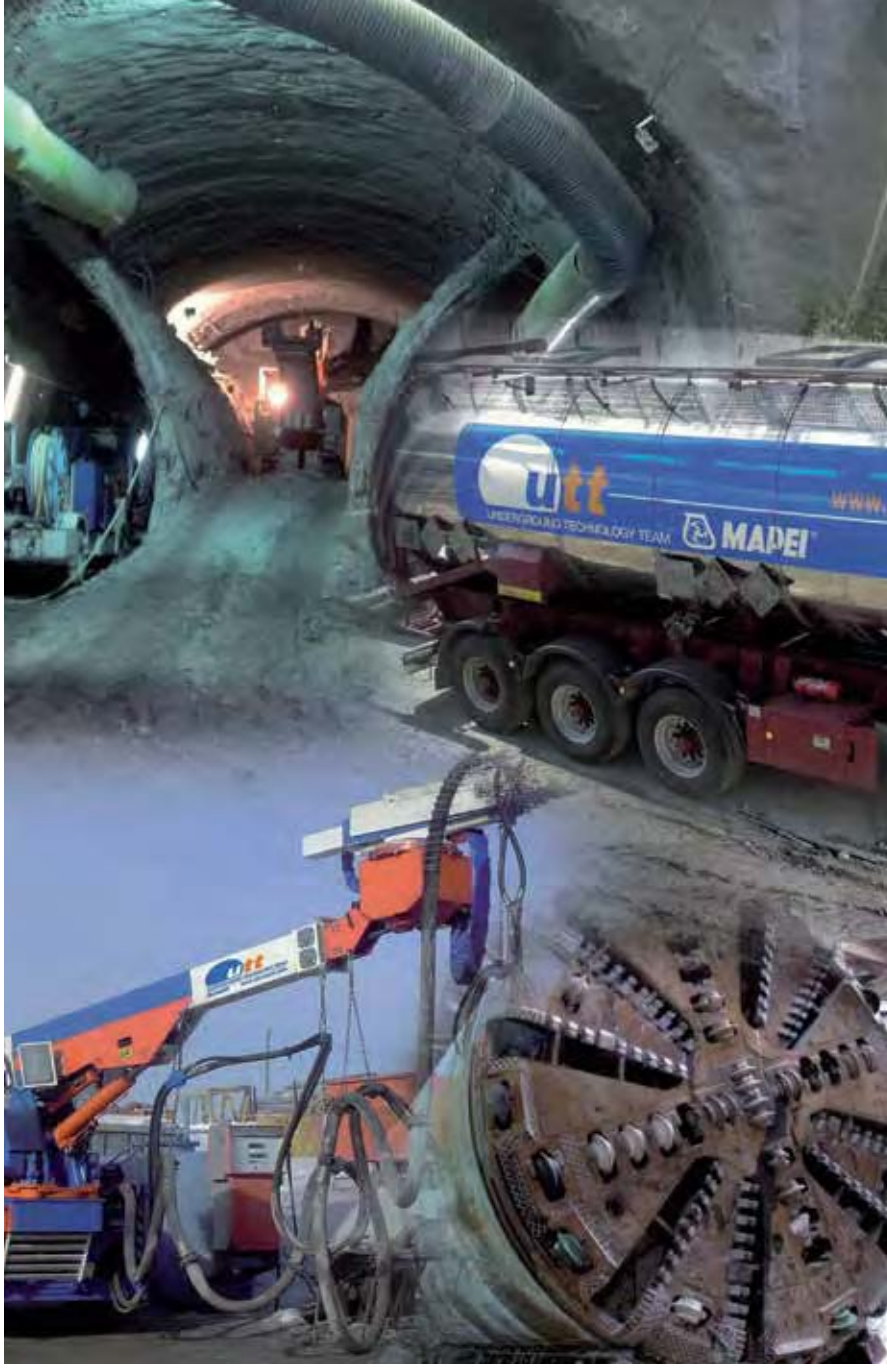

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Naylor Pipe Co
Booth: 213

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Booth: 622

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Nicholson Construction Co

Booth: 505

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Booth: 512

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Normet Americas, Inc
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Northwest Laborers-Employers Training Trust
Booth: 424

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The Safety and Hazard Awareness for Tunnels (SHAFT) courses are designed to teach skills for working safely in tunnels constructed using a tunnel boring machine (TBM). The program was developed by the Northwest Laborers-Employers Training Trust with input and consultation from several organizations. In addition to classroom lecture and discussion, participants have

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Parsons
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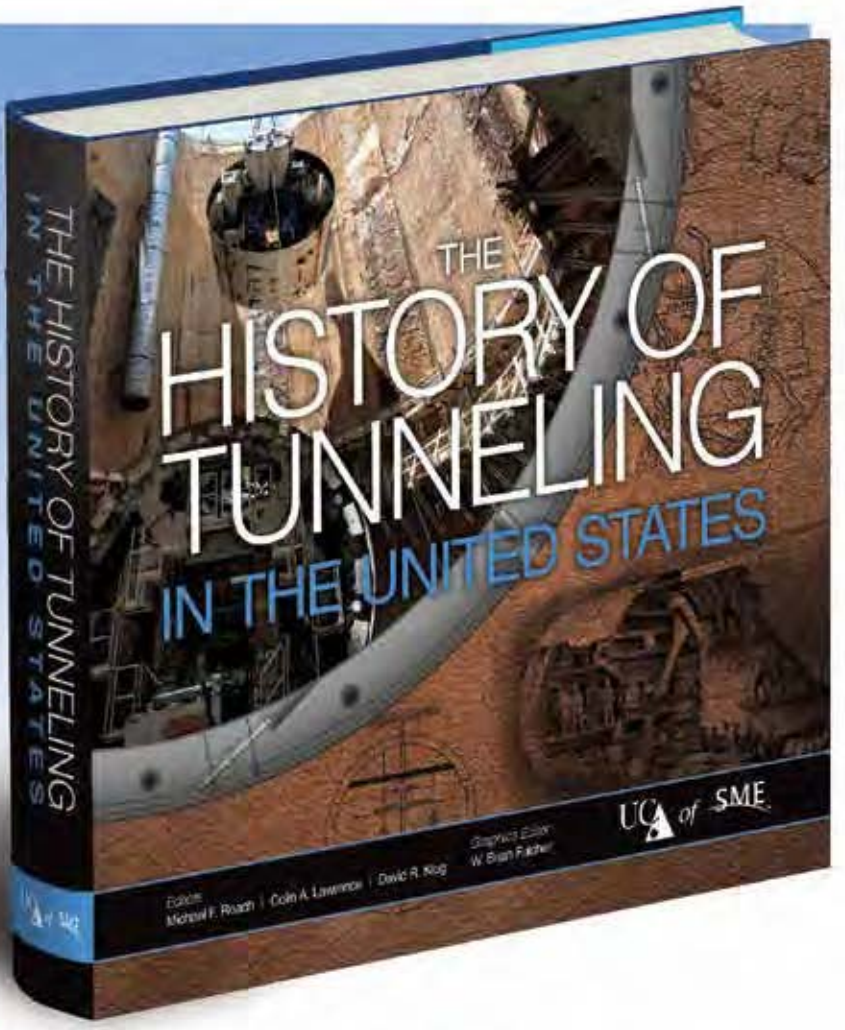
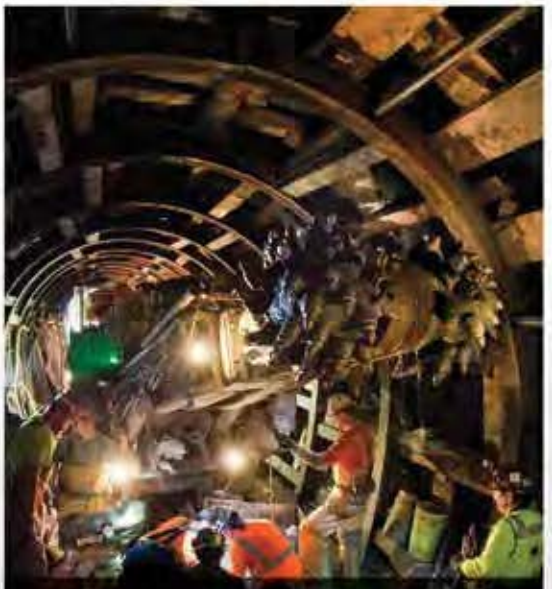
New Book Chronicles 200 Years of Tunneling in the United States





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Booth: 561

R.S.T. Instruments Ltd. has been in the engineering instrumentation industry since 1977. From conceptual designs of site-specific products to the exceptional post-sale calibration and repair service offered by the company's technical department, RST's commitment to client satisfaction is our ultimate organizational goal. RST takes much pride in providing custom engineered solutions to site-specific problems on a design-build basis. With ISO 9001 Certification, RST has a proven track record for quality, long-term stability, and product reliability. Our 26,000 sq.ft. modern facility incorporates CAD, CAM, and CNC manufacturing techniques. Such techniques assure high quality, at a reasonable cost, with timely delivery.

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Renesco Inc
Booth: 102

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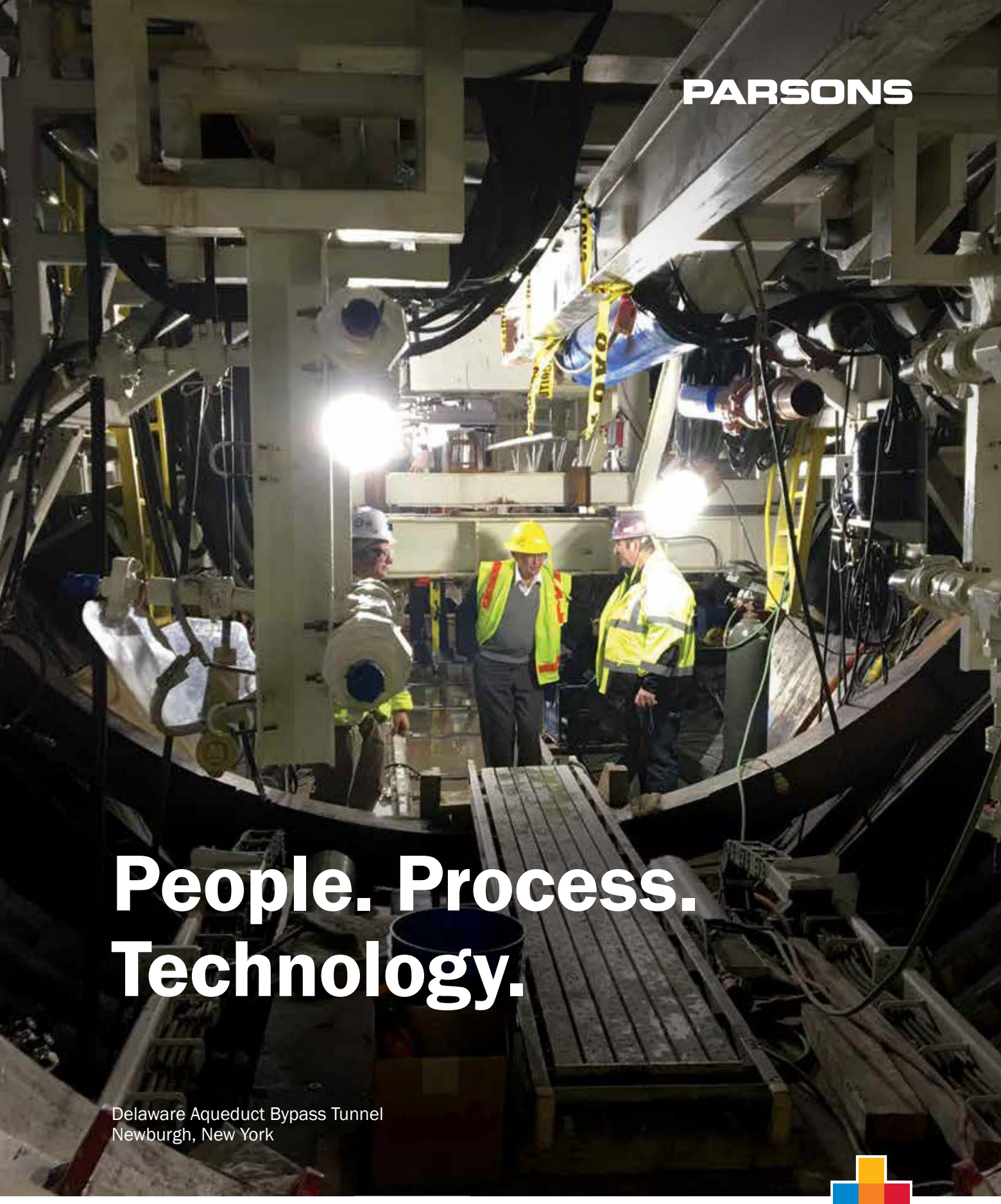
Richard Goettle, Inc. is a geotechnical engineering and construction company serving the United States. With over 60 years of experience, Goettle continues to be an industry leader specializing in design-build, earth retention systems, deep foundations, ground modification, and marine construction. Goettle services the tunneling industry by providing large diameter drilled shafts and earth retention systems, Including secant pile, soldier piles and lagging, and sheet pile systems. Solid engineering, state of the art equipment, innova-



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Shaft Drilling and Raiseboring Equipment

Main Office
12071 Hamilton Ave
Clncinnati, OH 45231 USA
Telephone: (513) 825-8100
Fax: (513) 825-8107
Email: info@goettle.com
www.goettle.com

Richway Industries
Booth: 416

Richway Industries is the premier manufacturer of equipment and foam concentrate for the production of cellular concrete. With equipment capable of producing up to 100 yards per hour, it's ASTM C869 foam concentrate, and over 40 years of foam generation and manufacturing experience, Richway can help with all of your cellular concrete needs. Because foam concentrate formulation & production, as well equipment design & production, are done in our own facility, we can also provide solutions for other aspects of your business. Richway knows foam and equipment.

Products & Services
Grouting Services, Equipment and Materials
Lubricants for TBM
Tunnel Boring Equipment
Tunnel Lining and Support Materials
Underground Excavation Services and Equipment

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Fax: (319) 987-2251
www.cretefoamer.com

Rite Geosystems
Booth: 209

Instrumentation and Monitoring Solution Provider. Geotechnical, Structural and Environmental Instrumentation Manufacturer. Online Cloud Based Automated Data Acquisition Solutions.

Products & Services
Instrumentation Equipment and Services

Main Office
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Pittsburgh, PA 15216 USA
Telephone: (412) 680-2526
Email: melih@ritegeosystems.com
www.ritegeosystems.com

ROBODRILL
Booth: 222

ROBODRILL is specialized in the design, the manufacture and the rental of underground drilling rigs. With a fleet of more than 100 jumbos, from 1 to 3 booms, automated and manual, we are committed to projects all over the world. Along with the machines, we also provide jumbos servicing, spare parts inventory,supervisors, and experienced operators for short or long duration projects.

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Rock Drills
Shaft Drilling and Raiseboring Equipment
Underground Excavation Services and Equipment

Main Office
5 Rue Jean Perrin
Genas, 69740 France
Telephone: +33 4 72 79 00 20
Fax: +33 4 72 79 00 29
www.robodrill-sa.com/

Rocscience, Inc

Booth: 310

Founded in 1996, Rocscience is a world leader in developing 2D and 3D software for civil, mining, and geotechnical engineers. For over 20 years, we've built on leading-edge research to create the best geotechnical software available. As engineers ourselves, we know the importance of having accurate, reliable, and easy-to-use software, so we constantly develop and refine our products to make solutions that work for you. Explore our comprehensive suite of tools used by over 7,000 engineers around the world for slope stability, excavation design, and geotechnical analysis.

Products & Services

Computer Hardware and Software
Geological, Geotechnical Services and Equipment

Main Office

54 St Patrick St
Toronto, ON M5T1V1 Canada
Telephone: (416) 698-8217
Email: software@rocscience.com
www.rocscience.com

Ruen Drilling, Inc

Booth: 304

See our ad on page 46

Ruen Drilling provides drilling services including surface, underground, and horizontal directional core drilling for the geotechnical, exploration and geothermal industries throughout the U.S., South America and Asia. Drilling equipment includes truck, track, skid, and helicopter supported core drills. Rig capacities are to 10,000 ft. vertical or angle and 3,000 ft. horizontal. Crews are all trained in achieving a high degree of core recovery for the client. Recent projects include: Devils Slide Tunnel, Irvington Tunnel, Caldecott Tunnel 4th bore, Route 9 Tunnel in Hong Kong, Highway 53 Tunnel in Puerto Rico, White Sands Missile Range and Mt. Olympus Pipeline No. 6.

Products & Services

Drilling Services and Equipment

Main Office

2320 River Rd
Clark Fork, ID 83811 USA
Telephone: (209) 988-4261
Fax: (209) 577-3157
www.ruendrilling.com

Sandvik Mining and Rock Technology

Booth: 628

Sandvik Mining and Rock Technology is a business area within the Sandvik Group and a global leading supplier of equipment and tools, service and technical solutions for the mining and construction industries. Application areas include rock drilling, rock cutting, crushing and screening, loading and hauling, tunneling, quarrying and breaking and demolition.

Products & Services

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Dust and Fume Control Technology
Mining Equipment
Roadheaders
Rock Drills
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Main Office
300 Technology Ct
Smyrna, GA 30082 USA
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Fax: (404) 589-2923
www.sandvik.com

Schauenburg Flexadux Corp
Booth: 636
See our ad on page 48

Schauenburg offers a complete line of ventilation products and ventilation design assistance for the mining and tunneling industry. Its products include forced air ventilation ducting, cassette systems for tunneling, flexible wire reinforced suction ducting, high pressure couplings, phenolic fiberglass ducting, inflatable stoppings, fans and dust collectors (wet or dry) as well as all fittings and adapters required to complete your ventilation system. In addition, Schauenburg carries gas detection radio cap lamps, brattice line curtains, tarps, brattice cable hangers, powder bags and cushions. All of its ventilation products are MSHA approved for underground use.

Products & Services
Dust and Fume Control Technology
Safety Products
Ventilation Systems, Materials and Equipment

Main Office
2233 Sanford Dr
Grand Junction, CO 81505 USA
Telephone: (970) 245-9400
Fax: (970) 245-9402
www.schauenburg-us.com

Schnabel – SWS
Tunneling and Underground Solutions

Schnabel - SWS
Booth: 624
See our ad on page 49

Schnabel Engineering and SWS Engineering USA have formed a strategic alliance to provide tunnel and underground solutions for complex infrastructure challenges in North America, specifically the United States and Canada. We have combined our project experience and expertise in tunnel and geostructural design, risk management, construction management and BIM. This association also brings significant experience and a sophisticated array of personnel to regions served by our more than 21 strategic offices in the United States and Canada.

Products & Services
Consulting Engineers
Consulting Environmental
Engineering Design and Services for Tunnels
Geological, Geotechnical Services and Equipment
Precast Concrete Linings
Underground Excavation Services and Equipment

Main Office
12720 Hillcrest Rd, Ste 585
Dallas, TX 75230 USA
Telephone: (972) 250-3322
Email: d.kochis@schnabel-sws.com
schnabel-sws.com

Schnabel Foundation Co
Booth: 541

Schnabel Foundation Company is a specialty geotechnical contractor that has been designing and constructing earth retention and deep foundation projects since 1959. Schnabel has a wide range of design and construction methods to provide the tunneling industry with the best possible circular access shaft or water cutoff retention system. These methods include secant piles, jet grouting and soil mixing, along with more conventional earth support systems and micropile foundations. Schnabel's numerous offices throughout the United States and in-house design capabilities allow a tailored fit system for project specific needs.

SoilFreeze

ENGINEERING SOLID GROUND

Applied Innovation. Proven Solutions.

Everyone knows that ground freezing succeeds in extremely difficult soil conditions where other excavation support methods are not feasible. Everyone also knows that soil freezing is one of only a handful of shoring methods can eliminate groundwater infiltration. But did you also know advancements in freeze technology and refinements in our freeze equipment has made SoilFreeze more mobile, versatile, and more cost efficient than ever before? And that soil freezing is extremely eco-conscious?

So why wait for the worst soil conditions? Ground freezing can solve any ground support requirements and eliminate dewatering at the same time. SoilFreeze is a leading provider of efficient, environmentally friendly ground freezing solutions. Installations can be designed, installed, and maintained for projects lasting a few weeks, or for several years. We serve both the private and public sectors and have a substantial list of successful projects and clients.

The Industry Leader in Frozen Soil Technologies

- **STRUCTURAL SHORING**
- **GROUNDWATER CUTOFF**
- **ENVIRONMENTAL REMEDIATION**

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Mining

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Products & Services
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Drilling Services and Equipment
Ground Improvement Equipment and Services
Grouting Services, Equipment and Materials
Jet Grouting Equipment and Services
Underground Excavation Services and Equipment

Main Office
45240 Business Ct, Ste 250
Sterling, VA 20166 USA
Telephone: (703) 742-0020
Fax: (703) 742-3319
Email: info@schnabel.com
www.schnabel.com

Shannon & Wilson, Inc
Booth: 206

Since 1954, Shannon & Wilson has been a pioneer in developing effective underground solutions to complex site development problems. This includes geotechnical assessments, GBRs, design, plans, specifications, construction management, and expert witness support on over 700 soft ground and hard rock tunnel projects, ranging from trenchless to the world's largest bore tunnels. Resources include over 300 staff from the corporate headquarters in Seattle, Washington, and Branch Offices in Alaska, California, Colorado, Florida, Missouri, Oregon, Utah, Washington, and Wisconsin.

Shannon & Wilson offers services in geotechnical evaluations, tunnel assessments, groundwater and dewatering, instrumentation, environmental, and natural resource assessments.

Products & Services
Consulting Engineers
Consulting Environmental
Engineering Design and Services for Tunnels
Geological, Geotechnical Services and Equipment
Instrumentation Equipment and Services

Main Office
400 N 34th St, Ste 100
Seattle, WA 98103 USA
Telephone: (206) 632-8020
Fax: (206) 695-6777
www.shannonwilson.com

Branch Offices
Shannon & Wilson, Inc
1321 Bannock St, Ste 200
Denver, CO 80204 USA
Telephone: (303) 825-3800
Fax: (206) 695-6777
Email: mag@shanwil.com

Shannon & Wilson, Inc
664 W Broadway
Glendale, CA 91204 USA
Telephone: (818) 543-4560
Fax: (206) 695-6777
Email: rtd@shanwil.com

Shannon & Wilson, Inc
13400 Sutton Park Dr S, Ste 1401
Jacksonville, FL 32224 USA
Telephone: (904) 223-6676
Email: rjg@shanwil.com

Shannon & Wilson, Inc
2043 Westport Center Dr
St Louis, MO 63146 USA
Telephone: (314) 699-9660
Fax: (314) 699-9661
Email: tja@shanwil.com

Shannon & Wilson, Inc
3990 Collins Way, Ste 100
Lake Oswego, OR 97035 USA
Telephone: (503) 210-4750
Fax: (206) 695-6777
Email: rpp@shanwil.com

Shotcrete Technologies, Inc
Booth: 423

See our ad on page 50

STI has been providing innovative Shotcrete Products and Services to the mining and tunneling industry for over 30 years. ST Robotic Arm, which can be mounted on many types of carriers and our STI Alkali Free and Shotset 250 Liquid Accelerators. STI's new shaft lining (vertical lining) technology - Centrifugal System and Double Nozzle Shaftlining Systems are the latest in Shaftlining Technology. STI's knowledgeable team of professionals provide everything from a Shotcrete System, help with a mix design, to testing and training based on your specific needs - mega projects to small mines. We support you from start to finish!

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Shotcrete Equipment, Supplies, and Services
Tunnel Lining and Support Materials

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Fax: (303) 567-4605
Email: info@shotcretetechnologies.com
www.shotcretetechnologies.com

Sika Corporation
Booth: 610

Sika Corporation is a specialty chemicals company with a leading position in the development and production of systems and products for bonding, sealing, damping, reinforcing and protecting in the building sector and automotive industry. For tunneling, Sika offers a wide variety of products such as chemical ad-

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WASHINGTON DC
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JUNE 24-27

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Every tunnel stands as evidence of problems solved, obstacles overcome, and partnerships solidified. Our drive has always been—and will continue to be—meeting our customers' challenges head-on. Visit us at NAT to learn more about how The Robbins Company is utilizing forward-thinking tunneling methods to carve new paths in the tunneling industry.

Robbins
RELIABLE | RESPONSIVE

mixtures for concrete, repair and protection products, waterproofing products and equipment for shotcrete. Sika has subsidiaries in 100 countries around the world and manufactures in over 200 factories. Its more than 18,000 employees generated annual sales of CHF 6.25 billion in 2017.

Products & Services
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Grouting Services, Equipment and Materials
Shotcrete Equipment, Supplies, and Services

Main Office
201 Polito Ave
Lyndhurst, NJ 07071 USA
Telephone: (201) 933-8800
Fax: (201) 933-6225
usa.sika.com

Simem Underground Solutions, Inc
Booth: 417

The team at Simem Underground Solutions has over 30 years experience providing fully automated material handling systems for TBM bi-component grout, hydrated bentonite, lightweight cellular grout, shotcrete, concrete and mining backfill. SUS manufactures colloidal mixers, pumping and delivery systems, as well as the automation and controls package. Concepts are specifically tailored to the customer's needs and include complete engineering, design and fabrication of all mechanical, structural and electrical systems. Services range from preliminary engineering and case studies through to hands-on commissioning and field training with complete CAD documentation and support.

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Abbotsford, BC V2T 6H4 Canada
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Email: sales@simemug.com
www.simem.com

SIXENSE
Booth: 507

Soldata is a leading provider of automated real time instrumentation monitoring for geotechnical, structural and environmental projects. With 20 years of experience, Soldata has demonstrated expertise in large urban tunnel instrumentation projects in cities including Seattle, Washington DC, Los Angeles, Amsterdam, London, Budapest, Barcelona, Toronto, etc. Soldata is currently monitoring the largest TBM project in the world, the Alaskan Way viaduct replacement project, as well as the light rail "Northlink Project, both in Seattle.

Products & Services
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Geological, Geotechnical Services and Equipment
Instrumentation Equipment and Services

Main Office
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Bothell, WA 98011 USA
Telephone: (206) 588-1691
www.sixense-soldata.com/en/

Smith and Long - Tunnelling Division
Booth: 104

Main Office
115 Idema Rd
Markham, L3R 1A9 Canada
Telephone: (416) 391-0443
Fax: (416) 391-0621
www.smithandlong.com

SoilFreeze Inc
Booth: 116

See our ad on page 51

SoilFreeze Inc. provides temporary frozen soil shoring systems to support excavations and provide groundwater cut-off. Our technology can be used for; groundwater cut-off, in situ-isolation barriers, foundation excavation shoring, cross passages, adits, ground stabilization and more. We design, fabricate, install and maintain customized freeze systems for each client's needs. We serve both the private and public sectors and have a substantial list of successful projects and satisfied clients. SoilFreeze Inc. has advanced and refined freeze technology to create freeze systems that are mobile, reusable, and expandable to address the needs of any sized project in urban and remote locations.

Products & Services
Ground Freezing

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5931 238th St SE, Ste 201
Woodinville, WA 98072 USA
Telephone: (206) 261-0733
www.soilfreeze.com

Spendrup Fan Co
Booth: 528

Since 1968, Spendrup Fan Co. has designed and manufactured quality vane axial fans and accessories for all types of mining and industrial applications. Spendrup fans are designed to withstand the harshest environments. Fan casings are made of 5/16" steel. Impeller hubs are fabricated from mild steel. Impeller blades are 356-T6 hardness, to resist highly abrasive conditions. Spendrup Fan Co. designs fans to meet client specifications. Spendrup Fan can meet client needs, from MSHA Sch. 2-G, U/L approved explosion proof, marine duty, to fans that provide trouble-free service in high-temperature or corrosive environments.

Products & Services
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Ventilation Systems, Materials and Equipment

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Fax: (970) 242-6724
www.spendrupfanco.com

Stantec
Booth: 539

The Stantec community unites approximately 22,000 employees working in over 400 locations across six continents. We have successfully delivered more than 1,200 underground projects in the past five years. Our portfolio includes tunnels up to 33 feet in diameter and shafts up to 110 feet in diameter. Our recent experience includes the City of Atlanta's Raw Water Delivery System with 5 miles of 10-foot diameter tunnels, City of Ottawa's CSST project with 3.7 miles of 9.8-foot diameter tunnels, and Metro Crenshaw/LAX Transit Corridor with three underground stations connected by four reaches of twin-bored, 21-foot diameter tunnels totaling 2 miles.

Products & Services
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Geological, Geotechnical Services and Equipment

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Walnut Creek, CA 94597 USA
Telephone: (925) 941-1400
Fax: (925) 941-1401
www.stantec.com

Surecrete Inc
Booth: 226

See our ad on page 52

Surecrete Inc. is a supplier focusing on packaged cementitious materials, admixtures, placing equipment and related accessories to the heavy civil tunnel, geotechnical and mining markets. Product lines include Super Fine ultrafine cement and HNP nano-fine cement grouts as well as other specialized grouting materials. We also concentrate on supplying wet and dry shotcrete materials that are custom blended for specific applications by including fibers, accelerators, special cements, and additives. Our additives include rheology modifiers, waterproofing and repair materials. We also represent several major equipment manufacturers specializing in the mixing and placing of shotcrete, concrete, and grout.

Products & Services
Grouting Services, Equipment and Materials
Shotcrete Equipment, Supplies, and Services

Main Office
155 NE 100th St, Ste 300
Seattle, WA 98125 USA
Telephone: (206) 523-1233
Fax: (206) 524-6972
Email: jeff@surecrete.com
www.surecrete.com

TBM Supply

Booth: 524

Supplier factory new, used and surplus , carbon, stainless and PVC: pipe, valves, fittings. Grooved, Threaded, Flanged, Welded. Domestic, DIN, JIS replacement including actuation.

Products & Services

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Telephone: (855) 535-1555
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Technical Tunnelling Components LTD (TTC)

Booth: 218

Technical Tunnelling Components has over 40 years of experience manufacturing and supplying segment accessories such as connection bolts, grout/lifting sockets, segment packers and grommets along with the award winning Dowelock connection and alignment system, now with high shear options. TTC truly is the one stop shop for all precast segmental fixing and grouting systems. The in-house design and manufacturing capabilities that Tunnelling Accessories and Bosworth Plastics have can also offer bespoke products for challenging situations as well as the standard segment accessories. TTC are Supplying components worldwide with an impressive product portfolio along with an excellent service record.

Products & Services

Grouting Services, Equipment and Materials
Precast Concrete Linings
Segment Accessories
Tunnel Lining and Support Materials

Main Office

Unit K Radius Ct, Tungsten Pk
Hinckley, Leicester LE10 3BE United Kingdom
Telephone: +44 0 1455 234401
Fax: +44 0 1455 250578
www.ttcltd.org

Techni-Metal Systems

Booth: 402

We are a French specialist in manufacturing of Multi-service Vehicles for heavy load transportation for civil engineering jobsite. Thanks to our logistic optimization study and to our MSVs' multi-purpose frame adapted to any charge to be transported at the different phases of the jobsite, our customers optimize their investment.

Products & Services

Concrete Mixing and Transportation Equipment
Grouting Services, Equipment and Materials
Microtunneling Equipment, Tools, and Supplies
Shotcrete Equipment, Supplies, and Services
Tunnel Boring Equipment
Tunnel Haulage Systems

Main Office

Parc Rhône Vallée - Ile Chambenier Sud
Le Pouzin, France 7250 France
Telephone: +33 475 85 8531
Fax: +33 475 85 8535
Email: sales@tms-company.com
www.tms-company.com

Tenbusch, Inc

Booth: 516

Tenbusch, Inc. designs and manufactures custom tunneling and pipe jacking systems. Products include: shields, excavators, conveyors, spoil carts and track, jacking frames, hydraulic power units, bentonite/polymer lubrication systems, and backstops. Tenbusch also manufactures sliplining systems and pipe carriers. In addition to the fabrication and manufacture of high quality heavy equipment, it offers reconditioning and refurbishment of used heavy equipment, support and training with design and problem solving services centered around over 40 years experience with hydraulics, and underground construction equipment. Over 15 years in mechanical design, mechanical engineering, and stress analysis, solid modeling and 3-D CAD design capabilities.

Products & Services

Air Locks and Bulkheads
Conveyor Equipment and Systems
Fabrication Materials
Mining Equipment
Soft Ground Shields
Tunnel Boring Equipment

Main Office

PO Box 417
Lewisville, TX 75067 USA
Telephone: (972) 221-2304
Fax: (972) 221-2498
Email: info@tenbusch.com
www.tenbusch.com

Terratec

Booth: 530

TERRATEC is a world-renowned Australian-based designer and manufacturer of Tunnel Boring Machines, Raise Boring Machines and other custom-made equipment for tunneling and mining applications. TERRATEC's success is based on the experience and excellence of its engineering team, which includes engineers with more than 40 years' experience in the design and manufacture of tunneling and mining machines. TERRATEC is fully managed by engineers providing quick and efficient solutions to meet customer expectations. TERRATEC products are well-known in the industry as Robust, Durable and Safe, that must prevail in the design of any equipment in the extreme conditions encountered underground.

Products & Services

Conveyor Equipment and Systems
Earth Pressure Balance Machines
Rock TBM's
Shaft Drilling and Raiseboring Equipment
Tunnel Boring Equipment

Main Office

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Hobart, Tasmania 7000 Australia
Telephone: +61 362233282
Email: info@terratec.com.au
www.terratec.co

The Lane Construction Corporation

Booth: 623

See our ad on page 35

The Lane Construction Corporation is a leading U.S. construction company specializing in the transportation, infrastructure and energy industries. Lane's unique combination of capabilities includes public-private partnerships/innovative financing and joint ventures; large, complex design-build and bid-build projects; and the ability to produce and install asphalt, aggregates, and concrete. Lane is owned by global construction leader, Salini Impregilo.

Products & Services

Construction - Contracting Services
Underground Excavation Services and Equipment

Main Office

90 Fieldstone Crt
Cheshire, CT 6410 USA
Telephone: (203) 235-3351
www.laneconstruct.com

The PBE Group

Booth: 502

The PBE Group, founded over 45 years ago, is a global heavy industries technology company, unique in the vertical integration of its engineered solutions. Serving multiple markets including, mining, tunneling and construction, PBE is unparalleled in its range of internally designed and manufactured safety, communications and productivity systems. Through one supplier of all equipment and software, the customer benefits from the reliability, functionality and cost benefits only a true single source solution provider can deliver. PBE offers a designed for purpose, robust, advanced solution enabling data-driven decisions through PBE's suite of management and control software.

Products & Services

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Mining Equipment
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Ventilation Systems, Materials and Equipment

Main Office

9115 Harris Corners Pkwy, Ste 310
Charlotte, NC 28269 USA
Telephone: (704) 509-6747
www.pbegrp.com

The Robbins Company

Booth: 317

See our ad on page 53

The Robbins Company has led the tunneling industry for over 65 years with advanced, underground construction equipment. Robbins machines are customized to meet each project's unique specifications, delivering optimal results in the most difficult conditions. Robbins is a total supply company with offerings that range from machines and conveyors that overcome tunneling challenges in hard rock and soft ground to knowledgeable field service personnel. For a complete solution and unparalleled support on your next tunneling project, look no further than Robbins.

Products & Services

Conveyor Equipment and Systems
Earth Pressure Balance Machines
Microtunneling Equipment, Tools, and Supplies
Rock TBM's
Slurry Services and Machines
Tunnel Boring Equipment

Main Office

29100 Hall St
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Thompson Pipe Group - Flowtite

Booth: 408

Tough Flowtite® FRP pipe is made using the continuous filament-winding process, allowing for additional strength to meet your exact jacking, microtunneling, or sliplining needs. The pipe can be customized within a broad range of lengths, diameters, pressure grades and stiffness classes. Flow-Crete™ jacking pipe is also available, which combines the strength of reinforced concrete with the corrosion resistance and pressure capabilities of Flowtite® FRP. Flowtite® can be specified for both pressure and gravity applications, as well as for wastewater and hydroelectric penstock projects and more.

Products & Services

Underground Utility Materials and Operations

Main Office

18585 Samuels Rd
Zachary, LA 70791 USA
Telephone: (225) 658-6166
www.thompsonpipegroup.com

Tioga Air Heaters - Mobile Air

Booth: 560

See our ad on page 57

Tioga designs, manufactures, rents, and sells climate control and ventilation equipment to provide safe working environments for employees and allow for operations to continue. Our portable heating equipment is great for remote locations of areas where power and fuel are a challenge. Tioga's skid mounted equipment are built with powerful blowers to quickly heat large areas or push heated air greater distances to where it is required. Tioga's equipment is known for its reliability in harsh conditions and ease of use. Visit us to discuss your next application.

Products & Services

Ground Freezing
Ground Improvement Equipment and Services
Ventilation Systems, Materials and Equipment

Main Office

4810 Lilac Dr N
Minneapolis, MN 55429 USA
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Fax: (763) 525-9796
www.tiogahvac.com

Tolsa Wyoming Bentonite Inc

Booth: 547

Experts in Global solutions for the industrial sector. Our products are used in more than 250 different industrial applications as civil engineering, oil&gas, construction and a long list of many others. Our raw materials extracted on three continents, the special processes in our plants, along with extensive research in our laboratories and our experts technical support, are key factors that help us to develop the broadest and most distinct line of industrial products and additives in the clays sector.

Products & Services

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Geological, Geotechnical Services and Equipment
Grouting Services, Equipment and Materials
Lubricants for TBM
Shotcrete Equipment, Supplies, and Services
Underground Excavation Services and Equipment

Main Office

12050 Bucknum Rd, # 3
Casper, WY 86204 USA
Telephone: (716) 913-3123
Email: info@tolsa.com
www.tolsa.com/industrial/en

TRE ALTAMIRA Inc

Booth: 543

TRE ALTAMIRA is recognized as the global leader in ground monitoring using SAR (Synthetic Aperture Radar) satellite data providing detailed surface motion information for engineering activities during tunneling operations. Using our proprietary SqueeSAR™ algorithms the group analyses images, captured by radar satellites to measure ground deformation to millimeter accuracy: detecting and monitoring ground subsidence, uplift, landslides, surface expression of faults, and for verifying the stability of individual structures. TRE ALTAMIRA produces dynamic maps and a database of surface deformation that provides a quantitative understanding of ground response to natural and anthropogenic activities. We have offices in Vancouver, Milan and Barcelona.

Products & Services

Instrumentation Equipment and Services

Main Office

475 W Georgia St, Ste #410
Vancouver, BC V6B 4M9 Canada
Telephone: (604) 331-2512
www.tre-altamira.com

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Telephone: +34 93 183 57 50
Fax: +34 93 183 57 59
Email: sales.spain@tre-altamira.com

TRE ALTAMIRA s.r.l.
Ripa di Porta - Ticinese, 79
Milano, 20143 Italy
Telephone: +39 02 4343 121
Fax: +39 02 4343 1230
Email: sales.italy@tre-altamira.com

TREVIICOS

Booth: 545

TREVIICOS is a full service geotechnical and foundation contractor specializing in Dam Rehabilitation, Slurry Walls, Cutoff Walls, Secant Piles, Caissons, Jet Grouting, Deep & Shallow Mixing and Ground Improvement. Our vast experience in underground construction allows us to find innovative and cost effective solutions to even the most challenging construction projects. We serve our clients nationwide from our headquarters located in Charlestown, Massachusetts.

Products & Services

Construction - Contracting Services
Ground Improvement Equipment and Services
Grouting Services, Equipment and Materials
Jet Grouting Equipment and Services
Slurry Services and Machines
Underground Excavation Services and Equipment

Main Office

38 Third Ave, 3rd Fl
Charlestown, MA 02129 USA
Telephone: (617) 241-4800
Fax: (617) 241-4801
Email: info@treviicos.com
www.treviicos.com

Tsurumi Pump

Booth: 563

Products & Services

Microtunneling Equipment, Tools, and Supplies
Mining Equipment
Pumps and Pumping Equipment
Slurry Services and Machines

Main Office

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Offering North America's largest and most reliable HVAC Rental Solutions for Tunneling, Mining and other Industrial Markets. Our solutions provide heat in North America's extreme cold regions, cooling for tunnels, shafts and processes, and ventilation to improve work conditions and employee safety.

COOLING SOLUTIONS

- Air-Cooled Chillers
- Water-Cooled Chillers
- Cooling Towers
- Air Conditioners

HEATING SOLUTIONS

- Indirect-Fired Heaters
- Direct-Fired Heaters
- Portable, Self-Contained Heaters
- Air Handlers

MARKETS SERVED

- Tunneling
- Infrastructure
- Mining
- Shafts
- Our heat and cooling solutions are used independently or in conjunction with high velocity, high volume fans to deliver a safe, well ventilated, climate controlled work environment for your employees and to ensure continuous operation of your project.

(800) 218-4642 • www.TiogaAirHeaters.com • Email: salesinfo@TiogaAirHeaters.com

Tunnel Business Magazine (TBM)

Booth: 100

TBM: Tunnel Business Magazine provides the North American tunneling industry with a trade magazine focusing on North American topics, projects and news. From large diameter tunneling to microtunneling, Tunnel Business Magazine, published by Benjamin Media, Inc., reports on the issues and topics important to the North American tunneling contractor, engineer and owner. Free subscriptions are available.

Products & Services

Educational
Publishers

Main Office

10050 Brecksville Rd
Brecksville, OH 44141 USA
Telephone: (330) 467-7588
Fax: (330) 468-2289
www.tunnelingonline.com

Tunneling Journal/Tunnelling Journal

Booth: 106

Tunnelling Journal delivers unrivalled editorial quality that features contemporary, lively, cutting edge articles with specific and unparalleled relevance to the tunnelling contractor, consultant, client and machine manufacturer. Published six times a year, the print copy is partnered with a constantly updated website and a fortnightly newsletter. We also publish Breakthrough magazine for the ITA Young Members, Australasian Tunnelling Society Journal, and organisers of the British Tunnelling Society Conference and the Cutting Edge Conference in partnership with SME. Visit our booth to pick up your complimentary copies of all our magazines and meet the team.

Products & Services

Educational
Publishers

Main Office

The Old Library , Webster House, Dudley Rd
Tunbridge Wells, Kent TN1 1LE United Kingdom
Telephone: +44 (0) 1892 522 585
Fax: +44 (0) 1892 529 041
Email: gary@tunnellingjournal.com
www.tunnellingjournal.com

Tunnels & Tunnelling

Booth: 114

With more than 40 years of service to the tunnelling industry, and packed with information about the business its customers are in, Tunnels & Tunnelling International remains the leading underground construction magazine worldwide. Since 1999 T&T offers T&T North America, a bi-monthly magazine dedicated to its customers' regional market, and the official publication of the Tunnelling Association of Canada (TAC). Each edition of T&T informs tunnelling professionals on every aspect of underground construction in five continents. Readers include consulting engineers, clients, contractors and manufacturers in 90 countries. Stay abreast of all developments in the tunnelling industry by subscribing to T&T.

Products & Services

Educational
Publishers

Main Office

John Carpenter House
London, EC4Y 0BS United Kingdom
Telephone: +44 (0) 20 7406 6584
Fax: +44 (0) 20 7936 6813
www.tunnelsonline.info

TunnelTalk

Booth: 108

Welcome to www.TunnelTalk.com - your gateway to tunneling on the web. Designed specifically as a web publication, TunnelTalk brings industry news, views and video reports directly to your internet device. A comprehensive editorial Archive is complimented by our industry Directory, Diary Dates, Job Opportunities, Equipment Sales and Procurement notices. Free weekly e-Alerts drive traffic to the site and, for industry advertisers, our readers are your next customers!

Products & Services

Educational
Publishers

Main Office

21001 N Tatum Blvd, Ste 1630-274
Phoenix, AZ 85050 USA
Telephone: (202) 470-3310
Email: tunneltalk@tunneltalk.com
www.tunneltalk.com

VMT USA

Booth: 308

As a driving technological force for more than 20 years, VMT has the experience, the capacities and the know-how to develop innovative system and product solutions that support construction companies all over the world to build tunnels and shafts of every size for ever more complex infrastructure projects: VMT's navigation systems for driving equipment, its production and logistics management system for segment production and further innovative system solutions for safety, monitoring and data management play key roles here. VMT products can be combined into efficient, modern, networked solutions that ensure streamlined processes and seamless quality assurance for every tunnel project.

Products & Services

Geological, Geotechnical Services and Equipment
Instrumentation Equipment and Services
Laser Guidance Systems
Precast Concrete Linings
Roadheaders
Tunnel Communication Systems and Equipment

Main Office

1613 132nd Ave E, Ste 200
Sumner, WA 98390 USA
Telephone: (253) 447-2399
Fax: (253) 863-9376
Email: info@vmt-us.com
www.vmt-us.com

Williams Form Engineering Corp

Booth: 657

Williams Form Engineering Corporation has been providing threaded steel bars and accessories for rock, soil and concrete anchors, post-tensioning systems, and concrete forming hardware systems in the construction industry for over 90 years. Our rock and soil anchor product line includes our Spin-Lock mechanical rock anchors, polyester resin anchors, multiple corrosion protection anchors, soil nails, strand anchors, Manta Ray soil anchors, Geo-Drill Hollow-Bar anchors, micro piles. For concrete anchoring we offer Spin-Lock anchors, undercut anchors, reusable anchors and cast-in-place anchors. We also have a full line of All-Thread Rebar for tie backs, micro piles and post-tensioning.

Products & Services

Concrete Reinforcement
Geological, Geotechnical Services and Equipment
Ground Improvement Equipment and Services
Steel Pipe
Tunnel Lining and Support Materials

Main Office

8165 Graphic Dr
Belmont, MI 49313 USA
Telephone: (616) 866-0815
Email: williams@williamsform.com
www.williamsform.com

Wisko America, Inc

Booth: 332

Wisko America Inc. has been installing flexible membrane in tunnels and underground structures since 1988 because the system works. With millions of square feet of flexible membranes successfully installed all over North America, Hawaii and Puerto Rico on over 90 projects, Wisko has a proven track record of providing dry underground structures to many clients and contractors.

Products & Services

Construction - Contracting Services
Tunnel Lining and Support Materials

Main Office

3935 Avion Park Ct, Ste A106
Chantilly, VA 20151 USA
Telephone: (703) 378-7858
Fax: (703) 378-7568
Email: pamela.moran@wiskoamerica.com
www.wiskoamerica.com

Worldsensing

Booth: 617

Make manual and cable readings an issue of the past: connect tunnels to the Internet of Things (IoT) and remotely monitor how the structure behaves. Loadsensing, the leading wireless monitoring system, is deployed in several sections of the Purple Line Metro Project in LA to enable the wireless monitoring of the stability of the tunnel and the surrounding buildings. Loadsensing is part of Worldsensing, a widely recognized global IoT pioneer. The technology provider delivers Operational Intelligence to traditional industries and cities. With offices in Barcelona, London and Los Angeles, Worldsensing is globally active with customers in over 50 countries.

Products & Services

Instrumentation Equipment and Services
Mining Equipment
Tunnel Communication Systems and Equipment

Main Office

C/ Viriat 47, 10th floor
Edificio Numancia 1
Barcelona, Barcelona 8014 Spain
Telephone: +34 93 418 05 85
www.worldsensing.com

WSP

Booth: 208

WSP is a leader in tunneling and underground construction, from San Francisco to Stockholm. The firm has participated in the design and construction of some of the longest, largest, deepest, and most complicated tunnels in the world, including tunnels built in hard rock, soft ground or mixed-face conditions, and using mining, boring, jacking, cut-and-cover, and immersed tunnel technology. Projects include the Second Avenue Subway in New York City; the Stockholm City Line; the Eurasia tunnel in Istanbul; and San Francisco's Central Subway. WSP employs 42,000 professionals in 500 offices across 40 countries.

Products & Services

Consulting Engineers
Engineering Design and Services for Tunnels
Geological, Geotechnical Services and Equipment

Main Office

444 S Flower St, Ste 800
Los Angeles, CA 90071 USA
Telephone: (212) 465-5215
Email: Frank.Pepe@wsp.com
www.wsp.com

Xylem

Booth: 556

Main Office

22 Floodgate Rd
Bridgeport, NJ 8014 USA
Telephone: (856) 467-3636
www.xyleminc.com

Zed Tunnel Guidance Ltd

Booth: 421

ZED manufactures and develops TBM guidance/navigation systems. More recently, ZED offers a redesigned system for long/curved pipejacks and a configuration that places the total station on the TBM backup rather than the tunnel wall, intended for smaller diameter TBM's where space is at a premium, especially along the backup walkway. The company provides comprehensive R&D services for electro-optical instrumentation for a variety of uses, from applications in the railway industry to vertical shaft alignment. Based in the UK, ZED has an enthusiastic team who provide a seasoned and prompt reaction to customer requirements and technological advances applicable to their products.

Products & Services

Instrumentation Equipment and Services
Laser Guidance Systems
Microtunneling Equipment, Tools, and Supplies

Main Office

Unit 1 Russell House, Molesey Rd
Walton on Thames, Surrey KT12 3PJ United Kingdom
Telephone: +44 (0) 1932 251 440
Fax: +44 (0) 1932 244 971
Email: Sales@zedtg.com
www.zedtg.com

New Listings

Comtrol International

Booth: 459

Description: Comtrol has built a reputation for manufacturing and distributing the highest quality communication and control systems to work in harsh environments. Our communication and control systems include Cellular over leaky feeder, VHF, UHF, Tracking and Gas Monitoring. Comtrol has invested decades of research to produce the best in class products that will keep your operation safe when it matters the most.

Products & Services

Control Systems
Environmental Control Equipment and Supplies
Geological, Geotechnical Services and Equipment
Safety Products
Tunnel Communication Systems and Equipment
Underground Utility Materials and Operations

Main Office

500 Pennsylvania Ave
Irwin, PA 15642
Phone (724) 864-3800
www.comtrol-corp.com

Abrasion and Impact Resistant Materials
JADCO Manufacturing Inc – Booth 555
KOSTEEL CO, LTD – Booth 336

Air Locks and Bulkheads
ASI Marine – Booth 522
Ballard Marine Construction – Booth 513
Tenbusch, Inc – Booth 516

Computer Hardware and Software
Amberg Technologies Ltd – Booth 653
BABENDERERDE ENGINEERS, LLC – Booth 216
GEOSLOPE International Ltd – Booth 553
Matrix Design Group – Booth 301
Plaxis Americas LLC – Booth 419
Rocscience, Inc – Booth 310
SIXENSE – Booth 507

Concrete Mixing and Transportation Equipment
Advanced Concrete Technologies – Booth 225
Amix Systems Ltd – Booth 227
King Shotcrete Solutions – Booth 511
Mining Equipment Ltd – Booth 506
Normet Americas, Inc – Booth 611
Putzmeister – Booth 400
Techni-Metal Systems – Booth 402

Concrete Reinforcement
Bekaert Maccaferri Underground Solutions – Booth 318
David R. Klug & Associates, Inc – Booth 418
Elasto Plastic Concrete – Booth 612
Fibermesh – Booth 509
GCP Applied Technologies – Booth 404
King Shotcrete Solutions – Booth 511
KOSTEEL CO, LTD – Booth 336
Mighty Shield Industries Sdn Bhd – Booth 603
Normet Americas, Inc – Booth 611
Sika Corporation – Booth 610
Williams Form Engineering Corp – Booth 657

Construction - Contracting Services
Ballard Marine Construction – Booth 513
Drill Tech Drilling & Shoring Inc – Booth 110
EC Applications - Tunnel Lining – Booth 302
Hayward Baker Inc – Booth 325
McMillen Jacobs Associates – Booth 316
Michels Corp – Booth 527
Moretrench – Booth 326
Mueser Rutledge Consulting Engineers – Booth 557
Promat International NV – Booth 600
Renesco Inc – Booth 102
Richard Goettle, Inc – Booth 601
Schnabel Foundation Co – Booth 541
Stantec – Booth 539
The Lane Construction Corporation – Booth 623
TREVIICOS – Booth 545
Wisko America, Inc – Booth 332

Consulting Engineers
AECOM – Booth 500
ASI Marine – Booth 522
BABENDERERDE ENGINEERS, LLC – Booth 216
CDM Smith – Booth 429
COWI North America – Booth 329
Dr. Sauer & Partners Corp – Booth 410
Everest Equipment Co – Booth 428
Gall Zeidler Consultants – Booth 427
Gomez International, Inc – Booth 523
Hager-Richter Geoscience, Inc – Booth 526
Hatch – Booth 412
HNTB Corp – Booth 223
McMillen Jacobs Associates – Booth 316
Mott MacDonald – Booth 451
MSP Structures Inc – Booth 605
Mueser Rutledge Consulting Engineers – Booth 557
Nexans AmerCable – Booth 622
Schnabel - SWS – Booth 624
Shannon & Wilson, Inc – Booth 206
Stantec – Booth 539
WSP – Booth 208

Consulting Environmental
Hager-Richter Geoscience, Inc – Booth 526
Hatch – Booth 412
HNTB Corp – Booth 223
Ocean Advanced Research – Booth 338
Schnabel - SWS – Booth 624
Shannon & Wilson, Inc – Booth 206
Stantec – Booth 539

Control Systems
Amberg Technologies Ltd – Booth 653
Amix Systems Ltd – Booth 227
Northern Light Technologies – Booth 518

Conveyor Equipment and Systems
Akkerman – Booth 633
Simem Underground Solutions, Inc – Booth 417
Tenbusch, Inc – Booth 516
Terratec – Booth 530
The Robbins Company – Booth 317

Drilling Services and Equipment
BAUER-Pileco Inc – Booth 546
Cascade Drilling L.P. – Booth 425
Crux Subsurface, Inc – Booth 406
Daigh Company, Inc – Booth 504
Derrick Equipment Co – Booth 608
Drill Tech Drilling & Shoring Inc – Booth 110
Malcolm Drilling Co Inc – Booth 619
Michels Corp – Booth 527
Palmieri S.p.A. – Booth 112
Richard Goettle, Inc – Booth 601
ROBODRILL – Booth 222
Ruen Drilling, Inc – Booth 304
Sandvik Mining and Rock Technology – Booth 628
Schnabel Foundation Co – Booth 541
Tolsa Wyoming Bentonite Inc – Booth 547

Dust and Fume Control Technology
ABC Industries, Inc – Booth 305
BASF Corporation – Booth 401
Englo, Inc, DBA Engart, Inc – Booth 618
Matrix Design Group – Booth 301
Sandvik Mining and Rock Technology – Booth 628
Schauenburg Flexadux Corp – Booth 636
Spendrup Fan Co – Booth 528

Earth Pressure Balance Machines
Akkerman – Booth 633
ASI Marine – Booth 522
Ballard Marine Construction – Booth 513
CDM Smith – Booth 429
Herrenknecht Tunnelling Systems USA, Inc – Booth 217
Lovsuns Tunneling Canada Ltd – Booth 411
Terratec – Booth 530
The Robbins Company – Booth 317

Educational
Northwest Laborers-Employers Training Trust – Booth 424
Tunnel Business Magazine – Booth TBM – Booth 100
Tunneling Journal/Tunnelling Journal – Booth 106
Tunnels & Tunnelling – Booth 114
TunnelTalk – Booth 108

Electrical - Generator-Motor, Wire-Cable
Line Power – Booth 616
Nexans AmerCable – Booth 622

Engineering Design and Services for Tunnels
AECOM – Booth 500
AIL Mining – Booth 510
BABENDERERDE ENGINEERS, LLC – Booth 216
CDM Smith – Booth 429
Dr. Sauer & Partners Corp – Booth 410
EC Applications - Tunnel Lining – Booth 302
Gall Zeidler Consultants – Booth 427
Hager-Richter Geoscience, Inc – Booth 526
HNTB Corp – Booth 223
JENNMAR Civil – Booth 607
KOSTEEL CO, LTD – Booth 336
McMillen Jacobs Associates – Booth 316
Mott MacDonald – Booth 451
MSP Structures Inc – Booth 605
Mueser Rutledge Consulting Engineers – Booth 557
Palmieri S.p.A. – Booth 112
Parsons – Booth 529
Promat International NV – Booth 600
R.S.T. Instruments Ltd – Booth 561
Renesco Inc – Booth 102
Schnabel - SWS – Booth 624
Shannon & Wilson, Inc – Booth 206
SIXENSE – Booth 507
Stantec – Booth 539
WSP – Booth 208

SHOWGUIDE exhibitor listings as of April 17, 2018

Environmental Control Equipment and Supplies
Agru America, Inc – Booth 300
Matrix Design Group – Booth 301
Northern Light Technologies – Booth 518
The PBE Group – Booth 502

Explosive Materials and Services
Daigh Company, Inc – Booth 504

Fabrication Materials
AIL Mining – Booth 510
Algaher S.A. – Booth 559
Tenbusch, Inc – Booth 516

Geological, Geotechnical Services and Equipment
AECOM – Booth 500
Amberg Technologies Ltd – Booth 653
Case Foundation - Bencor – Booth 323
CDM Smith – Booth 429
Crux Subsurface, Inc – Booth 406
Epiroc – Booth 501
Gall Zeidler Consultants – Booth 427
Geo-Instruments, Inc – Booth 327
Geocomp Corp/GeoTesting Express, Inc – Booth 312
Geokon, Inc – Booth 552
Hager-Richter Geoscience, Inc – Booth 526
McMillen Jacobs Associates – Booth 316
Measurand Inc – Booth 538
Mueser Rutledge Consulting Engineers – Booth 557
Nicholson Construction Co – Booth 505
Plaxis Americas LLC – Booth 419
R.S.T. Instruments Ltd – Booth 561
Rocscience, Inc – Booth 310
Schnabel - SWS – Booth 624
Shannon & Wilson, Inc – Booth 206
SIXENSE – Booth 507
Stantec – Booth 539
Tolsa Wyoming Bentonite Inc – Booth 547
VMT USA – Booth 308
Williams Form Engineering Corp – Booth 657
WSP – Booth 208

Ground Freezing
CDM Smith – Booth 429
Moretrench – Booth 326
Mueser Rutledge Consulting Engineers – Booth 557
SoilFreeze Inc – Booth 116
Tioga Air Heaters - Mobile Air – Booth 560

Ground Improvement Equipment and Services
Aerix Industries – Booth 542
Amix Systems Ltd – Booth 227
BAUER-Pileco Inc – Booth 546
Crux Subsurface, Inc – Booth 406
Hayward Baker Inc – Booth 325
Malcolm Drilling Co Inc – Booth 619
Moretrench – Booth 326
Mueser Rutledge Consulting Engineers – Booth 557
NKT Photonics Inc – Booth 512
Schnabel Foundation Co – Booth 541
Tioga Air Heaters - Mobile Air – Booth 560
TREVIICOS – Booth 545
Williams Form Engineering Corp – Booth 657

Grouting Services, Equipment and Materials
Aerix Industries – Booth 542
Alchemy-Spetec – Booth 659
Amix Systems Ltd – Booth 227
Avanti International – Booth 455
ChemGrout, Inc – Booth 224
Crux Subsurface, Inc – Booth 406
DSI Tunneling LLC – Booth 517
Epiroc – Booth 501
GCP Applied Technologies – Booth 404
Gomez International, Inc – Booth 523
Hayward Baker Inc – Booth 325
JENNMAR Civil – Booth 607
King Shotcrete Solutions – Booth 511
Malcolm Drilling Co Inc – Booth 619
Moretrench – Booth 326
Nicholson Construction Co – Booth 505
R.S.T. Instruments Ltd – Booth 561
Renesco Inc – Booth 102
Richard Goettle, Inc – Booth 601
Richway Industries – Booth 416
Schnabel Foundation Co – Booth 541
Sika Corporation – Booth 610
Simem Underground Solutions, Inc – Booth 417
Surecrete Inc – Booth 226
Techni-Metal Systems – Booth 402
Technical Tunnelling Components LTD (TTC) – Booth 218
Tolsa Wyoming Bentonite Inc – Booth 547
TREVIICOS – Booth 545

Hoists and Headframes
Mining Equipment Ltd – Booth 506

Hydraulic Hammers and Drills
BAUER-Pileco Inc – Booth 546
Brokk Inc – Booth 407
Daigh Company, Inc – Booth 504

Instrumentation Equipment and Services
BABENDERERDE ENGINEERS, LLC – Booth 216
Geo-Instruments, Inc – Booth 327
Geokon, Inc – Booth 552
Hager-Richter Geoscience, Inc – Booth 526
Measurand Inc – Booth 538
Northern Light Technologies – Booth 518
Poltinger Precision Systems GmbH – Booth 651
R.S.T. Instruments Ltd – Booth 561
Rite Geosystems – Booth 209
Shannon & Wilson, Inc – Booth 206
SIXENSE – Booth 507
TRE ALTAMIRA Inc – Booth 543
VMT USA – Booth 308
Worldsensing – Booth 617
Zed Tunnel Guidance Ltd – Booth 421

Jet Grouting Equipment and Services
Amix Systems Ltd – Booth 227
Drill Tech Drilling & Shoring Inc – Booth 110
Hayward Baker Inc – Booth 325
Malcolm Drilling Co Inc – Booth 619
Moretrench – Booth 326
Nicholson Construction Co – Booth 505
Schnabel Foundation Co – Booth 541
Simem Underground Solutions, Inc – Booth 417
TREVIICOS – Booth 545

Laser Guidance Systems
Amberg Technologies Ltd – Booth 653
Poltinger Precision Systems GmbH – Booth 651
VMT USA – Booth 308
Zed Tunnel Guidance Ltd – Booth 421

Lighting Systems
Matrix Design Group – Booth 301
Nightstick – Booth 629
Northern Light Technologies – Booth 518

Lubricants for TBM
American Chemical Technologies, Inc – Booth 604
BASF Corporation – Booth 401
DSI Tunneling LLC – Booth 517
Richway Industries – Booth 416
Tolsa Wyoming Bentonite Inc – Booth 547

Microtunneling Equipment, Tools, and Supplies
Akkerman – Booth 633
Algaher S.A. – Booth 559
ASI Marine – Booth 522
Ballard Marine Construction – Booth 513
BAUER-Pileco Inc – Booth 546
Brokk Inc – Booth 407
Derrick Equipment Co – Booth 608
Herrenknecht Tunnelling Systems USA, Inc – Booth 217
Lovsuns Tunneling Canada Ltd – Booth 411
McDowell Equipment Ltd – Booth 405
Nightstick – Booth 629
Palmieri S.p.A. – Booth 112
Poltinger Precision Systems GmbH – Booth 651
Techni-Metal Systems – Booth 402
The Robbins Company – Booth 317
Tsurumi Pump – Booth 563
Zed Tunnel Guidance Ltd – Booth 421

Mining Equipment
Antraquip Corp – Booth 311
BASF Corporation – Booth 401
Brookville Equipment Corp – Booth 430
Englo, Inc, DBA Engart, Inc – Booth 618
JENNMAR Civil – Booth 607
King Shotcrete Solutions – Booth 511
Line Power – Booth 616
McDowell Equipment Ltd – Booth 405
Messinger Bearings – Booth 606
Mining Equipment Ltd – Booth 506
Putzmeister – Booth 400
R.S.T. Instruments Ltd – Booth 561
Sandvik Mining and Rock Technology – Booth 628

SHOWGUIDE exhibitor listings as of April 17, 2018

Shotcrete Technologies, Inc – Booth 423
Tenbusch, Inc – Booth 516
The PBE Group – Booth 502
Tsurumi Pump – Booth 563
Worldsensing – Booth 617

Mucking Systems
Mining Equipment Ltd – Booth 506

Non-Explosive Mechanical Excavation
Alpine Equipment – Booth 211
Daigh Company, Inc – Booth 504
Drill Tech Drilling & Shoring Inc – Booth 110
Englo, Inc, DBA Engart, Inc – Booth 618
Malcolm Drilling Co Inc – Booth 619

Precast Concrete Linings
Agru America, Inc – Booth 300
Algaher S.A. – Booth 559
BASF Corporation – Booth 401
Bekaert Maccaferri Underground Solutions – Booth 318
Datwyler Sealing Technologies – Booth 214
David R. Klug & Associates, Inc – Booth 418
EC Applications - Tunnel Lining – Booth 302
Everest Equipment Co – Booth 428
GCP Applied Technologies – Booth 404
KOSTEEL CO, LTD – Booth 336
Mighty Shield Industries Sdn Bhd – Booth 603
Schnabel - SWS – Booth 624
Technical Tunnelling Components LTD (TTC) – Booth 218
VMT USA – Booth 308

Publishers
Tunnel Business Magazine – Booth TBM – Booth 100
Tunneling Journal/Tunnelling Journal – Booth 106
Tunnels & Tunnelling – Booth 114
TunnelTalk – Booth 108

Pumps and Pumping Equipment
Avanti International – Booth 455
BAUER-Pileco Inc – Booth 546
Gomez International, Inc – Booth 523
Grindex Pumps – Booth 626
King Shotcrete Solutions – Booth 511
Putzmeister – Booth 400
Simem Underground Solutions, Inc – Booth 417
Tsurumi Pump – Booth 563

Rail Products
Algaher S.A. – Booth 559
Brookville Equipment Corp – Booth 430
JENNMAR Civil – Booth 607

Roadheaders
Alpine Equipment – Booth 211
Antraquip Corp – Booth 311
Poltinger Precision Systems GmbH – Booth 651
Sandvik Mining and Rock Technology – Booth 628
VMT USA – Booth 308

Rock Drills
Brokk Inc – Booth 407
DSI Tunneling LLC – Booth 517
Epiroc – Booth 501
ROBODRILL – Booth 222
Sandvik Mining and Rock Technology – Booth 628

Rock TBM's
Akkerman – Booth 633
CDM Smith – Booth 429
Herrenknecht Tunnelling Systems USA, Inc – Booth 217
Lovsuns Tunneling Canada Ltd – Booth 411
Messinger Bearings – Booth 606
Terratec – Booth 530
The Robbins Company – Booth 317

Rotary Drum Cutters
Alpine Equipment – Booth 211
Antraquip Corp – Booth 311
Brokk Inc – Booth 407

Safety Products
ABC Ventilation Systems – Booth 322
Matrix Design Group – Booth 301
Nightstick – Booth 629
NKT Photonics Inc – Booth 512
Ocean Advanced Research – Booth 338
Promat International NV – Booth 600
Schauenburg Flexadux Corp – Booth 636
The PBE Group – Booth 502

Scaling
Alpine Equipment – Booth 211
Antraquip Corp – Booth 311
Brokk Inc – Booth 407
Normet Americas, Inc – Booth 611

Segment Accessories
Algaher S.A. – Booth 559
Datwyler Sealing Technologies – Booth 214
Nightstick – Booth 629
Technical Tunnelling Components LTD (TTC) – Booth 218

Shaft Drilling and Raiseboring Equipment
Case Foundation - Bencor – Booth 323
Epiroc – Booth 501
Herrenknecht Tunnelling Systems USA, Inc – Booth 217
Malcolm Drilling Co Inc – Booth 619
Michels Corp – Booth 527
Nicholson Construction Co – Booth 505
Palmieri S.p.A. – Booth 112
Renesco Inc – Booth 102
Richard Goettle, Inc – Booth 601
ROBODRILL – Booth 222
Terratec – Booth 530

Shotcrete Equipment, Supplies, and Services
BASF Corporation – Booth 401
GCP Applied Technologies – Booth 404
JENNMAR Civil – Booth 607
King Shotcrete Solutions – Booth 511
KOSTEEL CO, LTD – Booth 336
Mapei Corp – Booth 307
McDowell Equipment Ltd – Booth 405
Michels Corp – Booth 527
Normet Americas, Inc – Booth 611
Putzmeister – Booth 400
Shotcrete Technologies, Inc – Booth 423
Sika Corporation – Booth 610
Surecrete Inc – Booth 226
Techni-Metal Systems – Booth 402
Tolsa Wyoming Bentonite Inc – Booth 547

Slurry Services and Machines
Amix Systems Ltd – Booth 227
BAUER-Pileco Inc – Booth 546
Case Foundation - Bencor – Booth 323
Derrick Equipment Co – Booth 608
Michels Corp – Booth 527
The Robbins Company – Booth 317
TREVIICOS – Booth 545
Tsurumi Pump – Booth 563

Soft Ground Shields
Herrenknecht Tunnelling Systems USA, Inc – Booth 217
Tenbusch, Inc – Booth 516

Soil Conditioning Equipment and Materials
Alpine Equipment – Booth 211
Avanti International – Booth 455
Mapei Corp – Booth 307
NKT Photonics Inc – Booth 512
Normet Americas, Inc – Booth 611
Simem Underground Solutions, Inc – Booth 417

Steel Pipe
AIL Mining – Booth 510
JADCO Manufacturing Inc – Booth 555
Naylor Pipe Co – Booth 213
TBM Supply – Booth 524
Williams Form Engineering Corp – Booth 657

Survey Equipment and Lasers
Amberg Technologies Ltd – Booth 653
NKT Photonics Inc – Booth 512
Poltinger Precision Systems GmbH – Booth 651

Tunnel Boring Equipment
Akkerman – Booth 633
Ballard Marine Construction – Booth 513
Gomez International, Inc – Booth 523
Herrenknecht Tunnelling Systems USA, Inc – Booth 217
Lovsuns Tunneling Canada Ltd – Booth 411
Messinger Bearings – Booth 606
Palmieri S.p.A. – Booth 112
Poltinger Precision Systems GmbH – Booth 651

SHOWGUIDE exhibitor listings as of April 17, 2018

Richway Industries – Booth 416
Sandvik Mining and Rock Technology – Booth 628
Spendrup Fan Co – Booth 528
Techni-Metal Systems – Booth 402
Tenbusch, Inc – Booth 516
Terratec – Booth 530
The Robbins Company – Booth 317

Tunnel Communication Systems and Equipment

DSI Tunneling LLC – Booth 517
Innovative Wireless Technologies – Booth 643
Matrix Design Group – Booth 301
NKT Photonics Inc – Booth 512
Northern Light Technologies – Booth 518
R.S.T. Instruments Ltd – Booth 561
The PBE Group – Booth 502
VMT USA – Booth 308
Worldsensing – Booth 617

Tunnel Haulage Systems

Akkerman – Booth 633
McDowell Equipment Ltd – Booth 405
Mining Equipment Ltd – Booth 506
Techni-Metal Systems – Booth 402

Tunnel Lining and Support Materials

Agru America, Inc – Booth 300
AIL Mining – Booth 510
Algaher S.A. – Booth 559
Antraquip Corp – Booth 311
BASF Corporation – Booth 401
Bekaert Maccaferri Underground Solutions – Booth 318
ConShield Technologies – Booth 118
CTS Cordes tubes & seals GmbH & Co KG – Booth 422
Datwyler Sealing Technologies – Booth 214
David R. Klug & Associates, Inc – Booth 418
DSI Tunneling LLC – Booth 517
EC Applications - Tunnel Lining – Booth 302
Elasto Plastic Concrete – Booth 612
Everest Equipment Co – Booth 428
GCP Applied Technologies – Booth 404
JENNMAR Civil – Booth 607
Kern Tunneltechnik SA – Booth 457
KOSTEEL CO, LTD – Booth 336
Mighty Shield Industries Sdn Bhd – Booth 603
MSP Structures Inc – Booth 605
Normet Americas, Inc – Booth 611
Promat International NV – Booth 600
Renesco Inc – Booth 102
Richway Industries – Booth 416
Shotcrete Technologies, Inc – Booth 423
Technical Tunnelling Components LTD (TTC) – Booth 218
Williams Form Engineering Corp – Booth 657
Wisko America, Inc – Booth 332

Underground Excavation Services and Equipment

Alpine Equipment – Booth 211
Amberg Technologies Ltd – Booth 653
Brokk Inc – Booth 407
Daigh Company, Inc – Booth 504
Drill Tech Drilling & Shoring Inc – Booth 110
Englo, Inc, DBA Engart, Inc – Booth 618
Epiroc – Booth 501
Gomez International, Inc – Booth 523
Mapei Corp – Booth 307
McDowell Equipment Ltd – Booth 405
McMillen Jacobs Associates – Booth 316
Michels Corp – Booth 527
Nightstick – Booth 629
Richway Industries – Booth 416
ROBODRILL – Booth 222
Schnabel - SWS – Booth 624
Schnabel Foundation Co – Booth 541
The Lane Construction Corporation – Booth 623
Tolsa Wyoming Bentonite Inc – Booth 547
TREVIICOS – Booth 545

Underground Locomotives and Rail Haulage Equipment

Brookville Equipment Corp – Booth 430
Gomez International, Inc – Booth 523
McDowell Equipment Ltd – Booth 405

Underground Utility Materials and Operations

Avanti International – Booth 455
Line Power – Booth 616
Nightstick – Booth 629
NKT Photonics Inc – Booth 512
Promat International NV – Booth 600
TBM Supply – Booth 524
Thompson Pipe Group - Flowtite – Booth 408

Ventilation Systems, Materials and Equipment

ABC Industries, Inc – Booth 305
ABC Ventilation Systems – Booth 322
AIL Mining – Booth 510
Englo, Inc, DBA Engart, Inc – Booth 618
Epiroc – Booth 501
Mining Equipment Ltd – Booth 506
Naylor Pipe Co – Booth 213
Promat International NV – Booth 600
Schauenburg Flexadux Corp – Booth 636
Spendrup Fan Co – Booth 528
The PBE Group – Booth 502
Tioga Air Heaters - Mobile Air – Booth 560

Wastewater Management Products

Agru America, Inc – Booth 300
Avanti International – Booth 455
ConShield Technologies – Booth 118
Hobas Pipe USA – Booth 647

Water Treatment Plant and Materials

Agru America, Inc – Booth 300
Hobas Pipe USA – Booth 647
Moretrench – Booth 326

SHOWGUIDE exhibitor listings as of April 17, 2018

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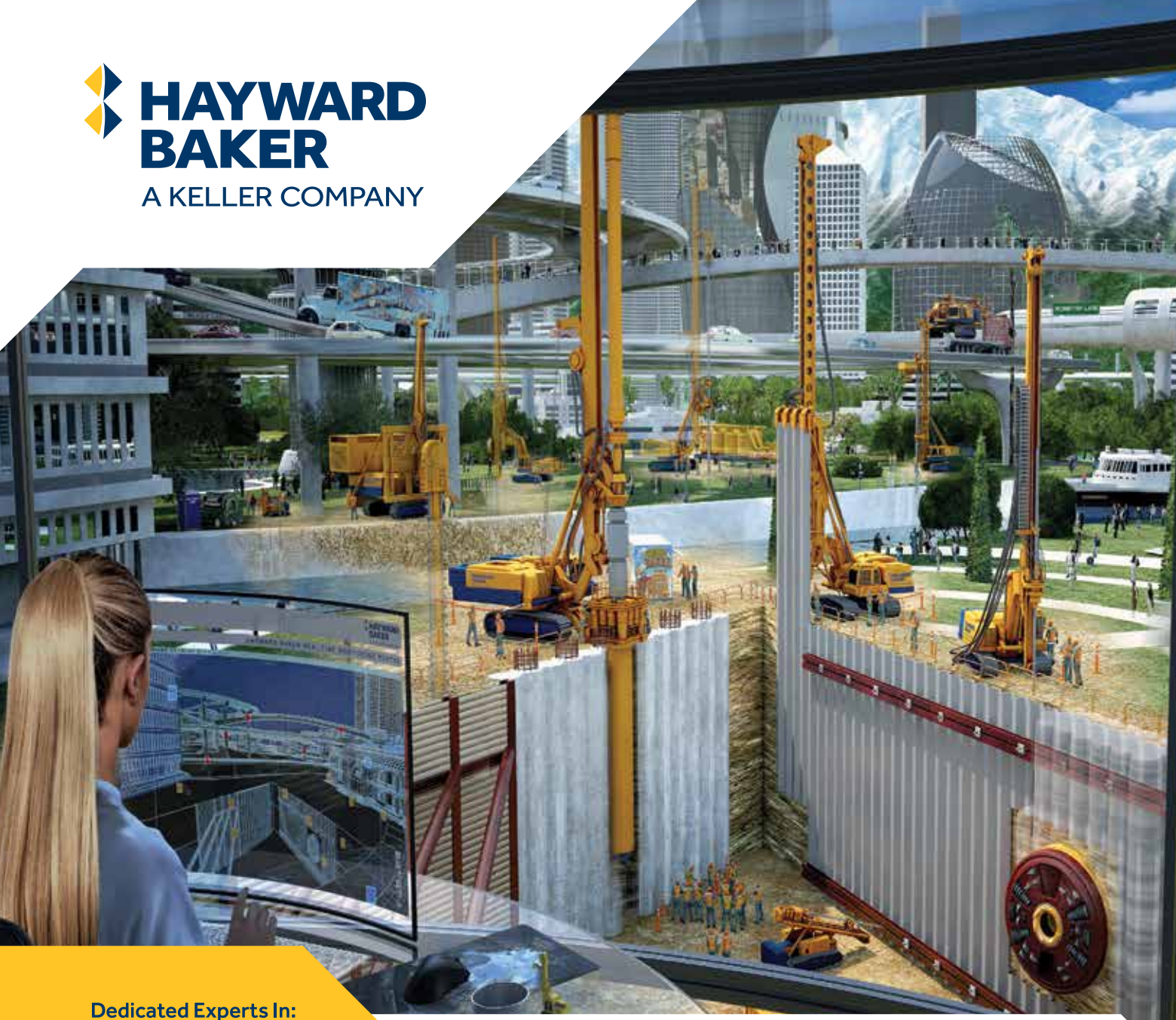

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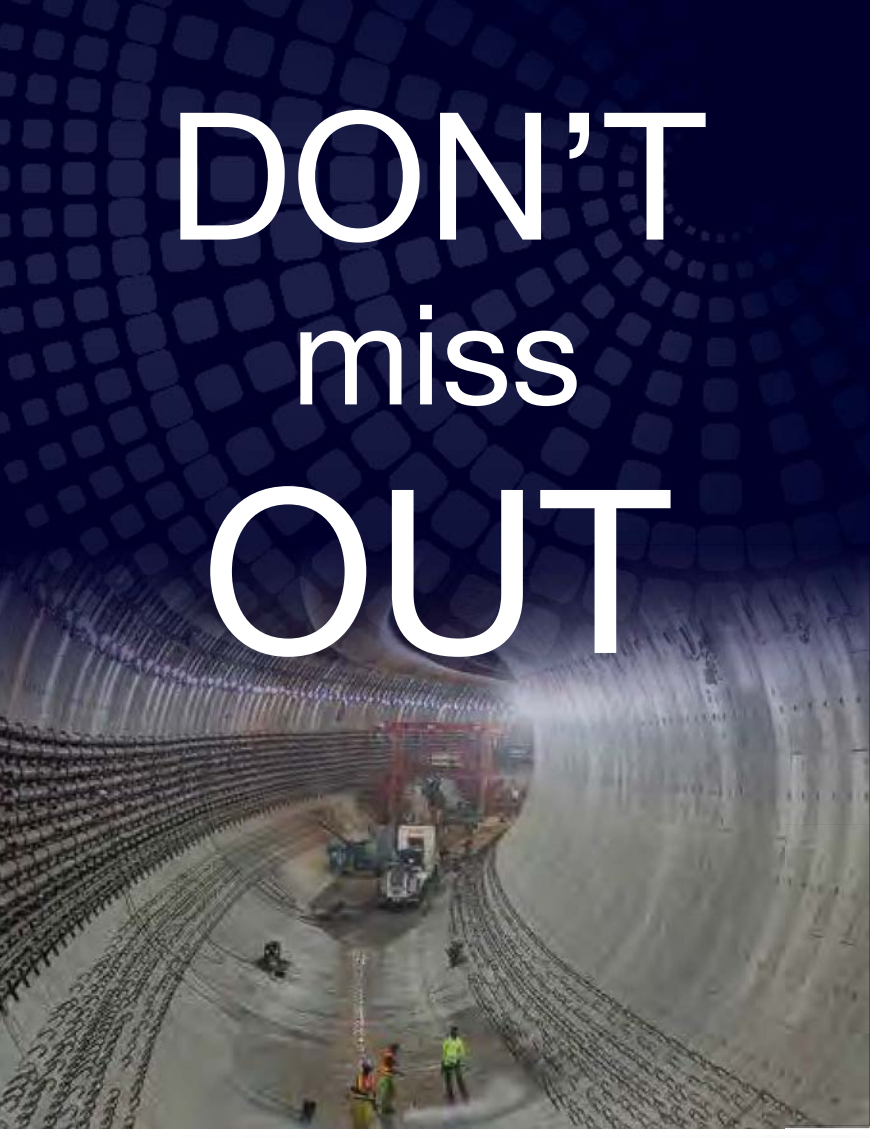

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